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Colloquium

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# Kilonova Detectability with Wide-Field Instruments

Eve A. Chase

February 7, 2022

LANL LA-UR: ##-#####

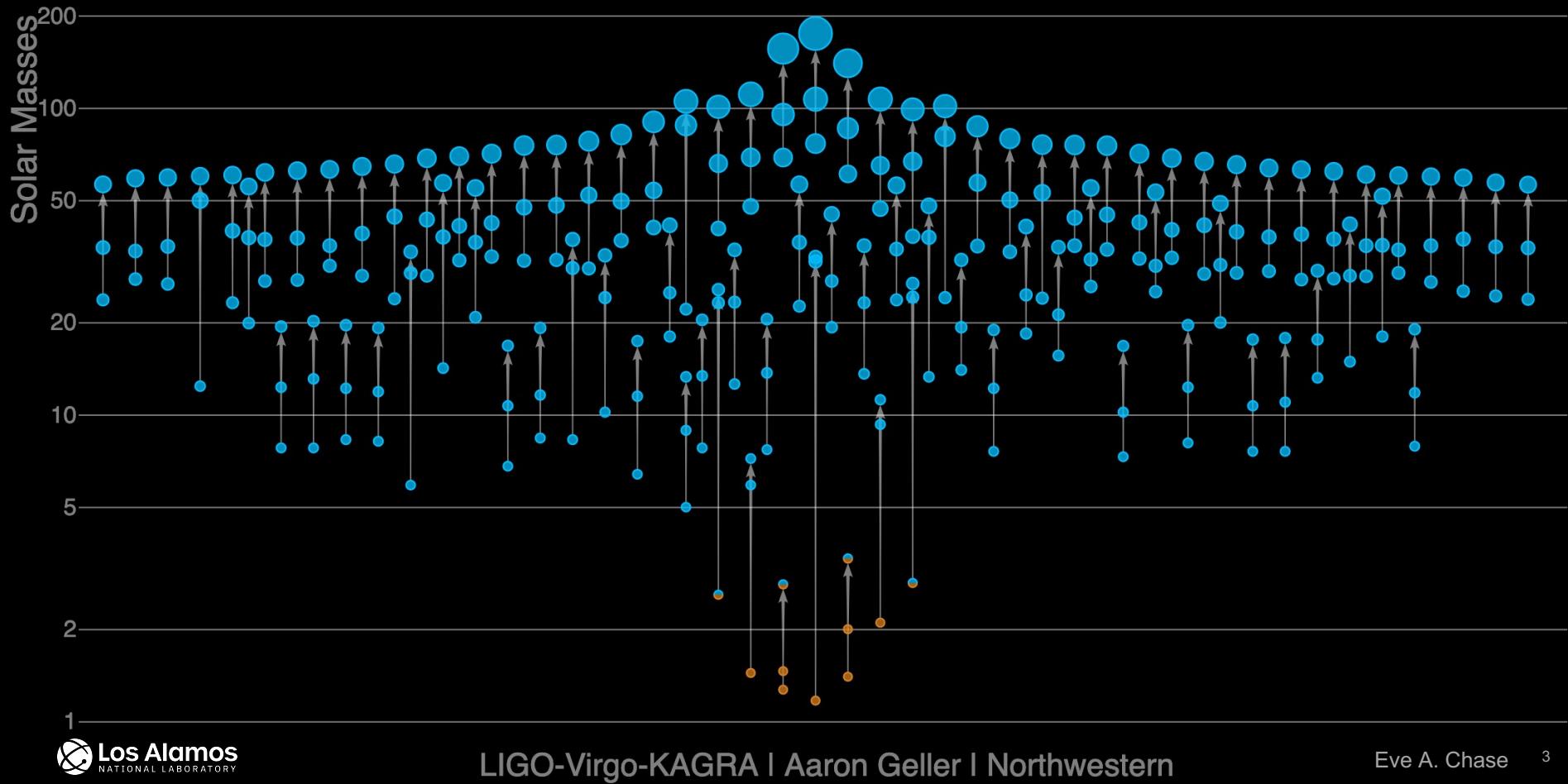
# Chase et al. 2022

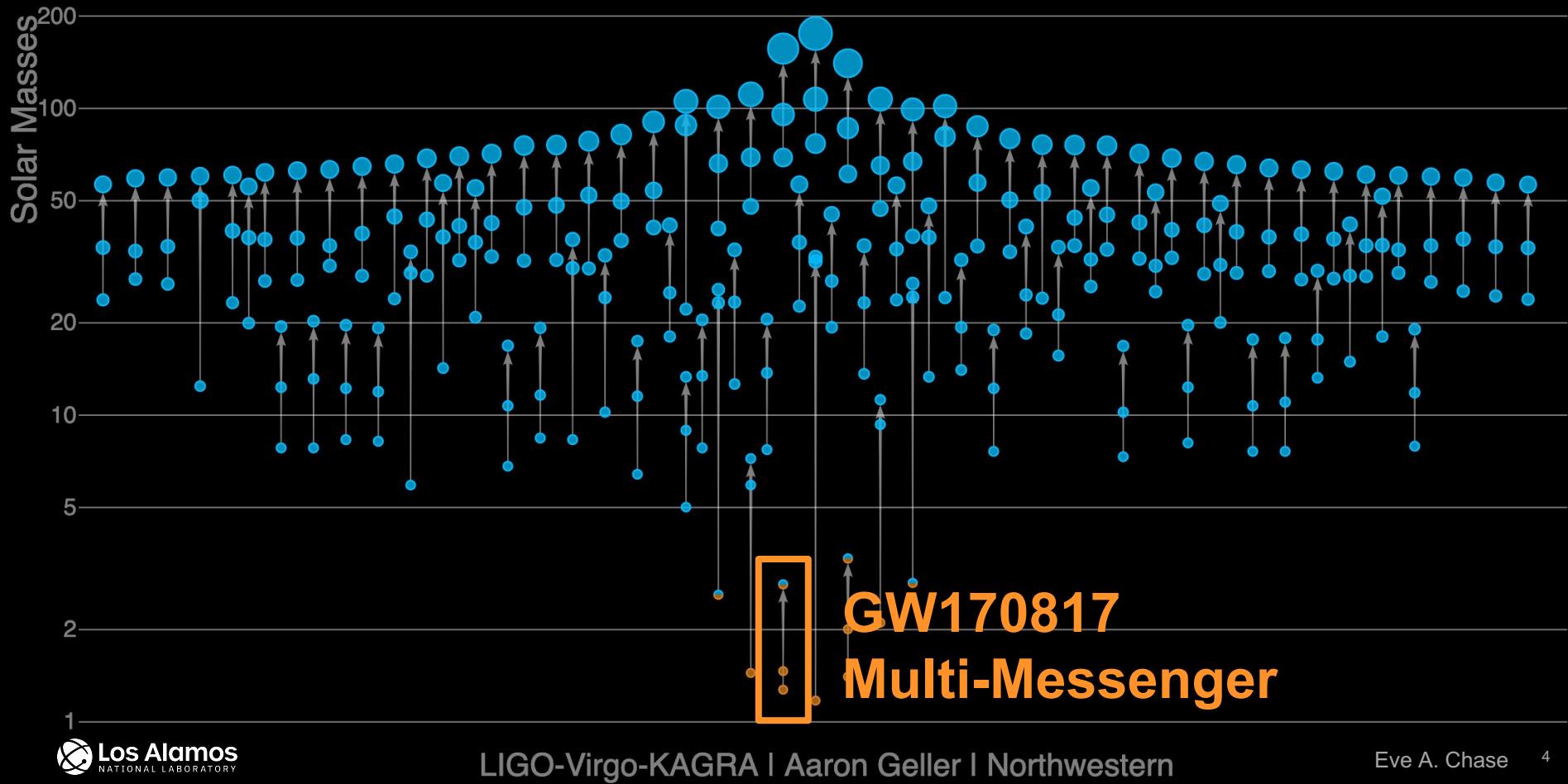
Accepted by ApJ

arXiv: 2105.12268

## Collaborators:

Brendan O'Connor, Chris Fryer, Eleonora Troja, Oleg Korobkin, Ryan Wollaeger, Marko Ristic (RIT), Chris Fontes, Aimee Hungerford, and Angela Herring





Painting Credit:  
Karelle Siellez

# Neutron Star Mergers

Gravitational  
Waves

EM  
Emission

# Neutron Star Mergers

General relativity

Gravitational  
Waves

EM  
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# Neutron Star Mergers

General relativity

Stellar astrophysics

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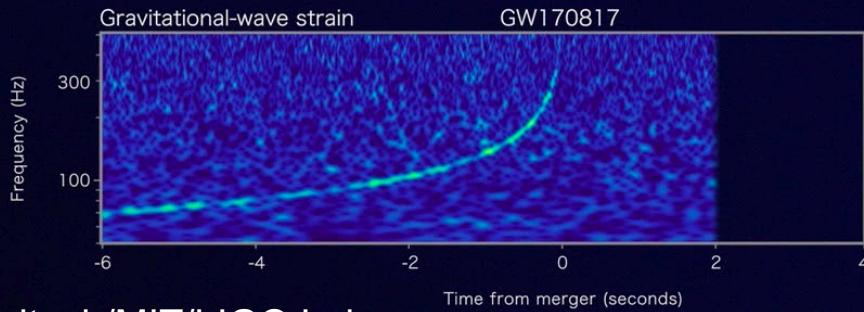
EM  
Emission

Painting Credit:  
Karelle Siellez

# Neutron Star Mergers

Gravitational  
Waves

LIGO



Credit: NASA GSFC & Caltech/MIT/LIGO Lab

Painting Credit:

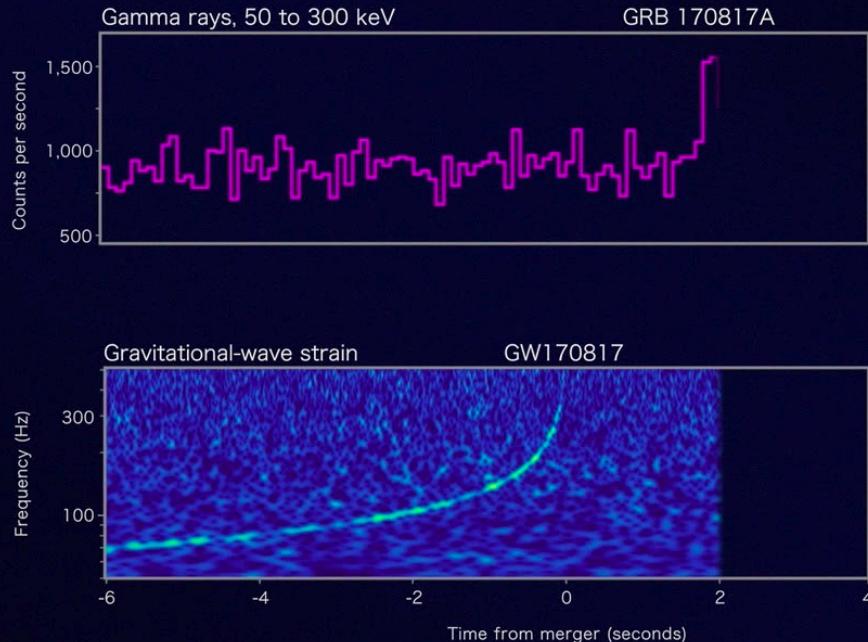
Karelle Siellez

# Neutron Star Mergers

Fermi



LIGO

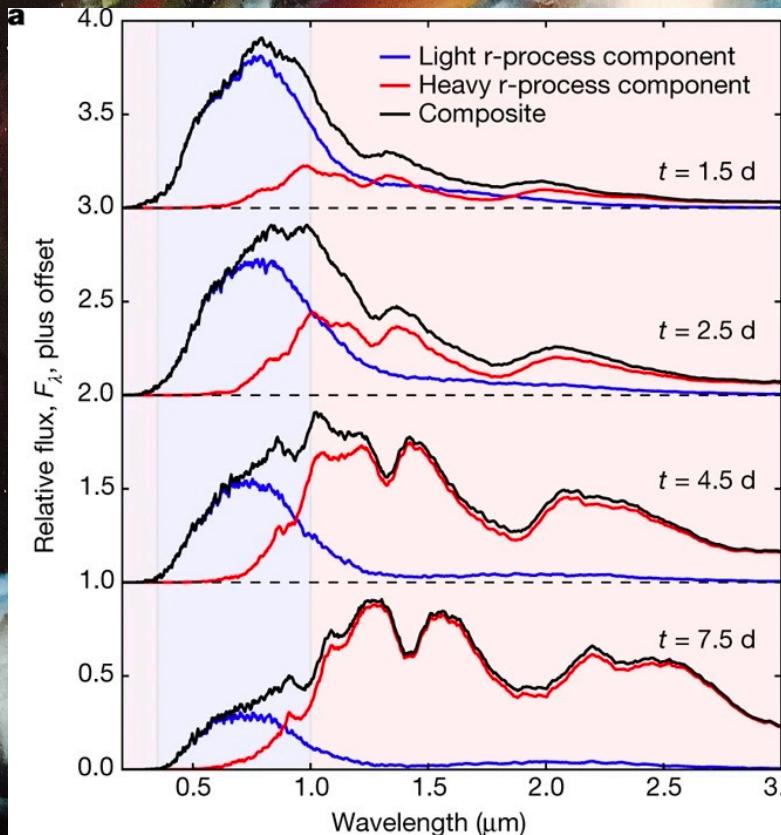


Gravitational Waves

Gamma-ray Burst

Credit: NASA GSFC & Caltech/MIT/LIGO Lab

# Neutron Star Mergers



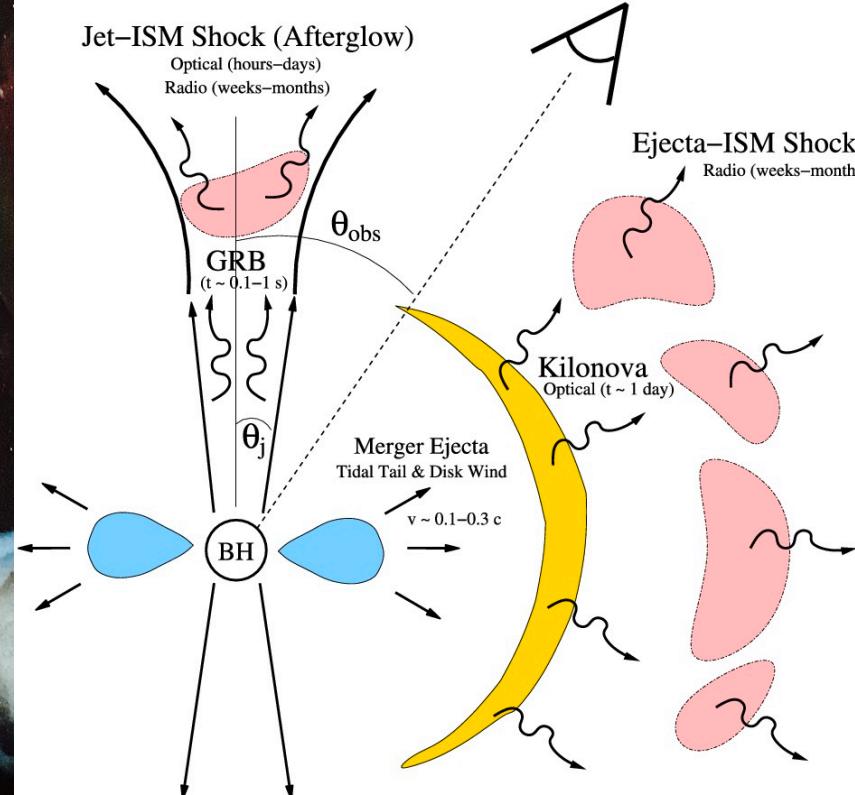
Kasen et al. 2017; arXiv: 1710.05463

Gravitational  
Waves

Gamma-ray  
Burst

Kilonova

# Neutron Star Mergers



Metzger & Berger 2012; arXiv: 1108.6056

Gravitational  
Waves

Gamma-ray  
Burst

Kilonova

Afterglow

# Neutron Star Mergers

General relativity

Stellar astrophysics

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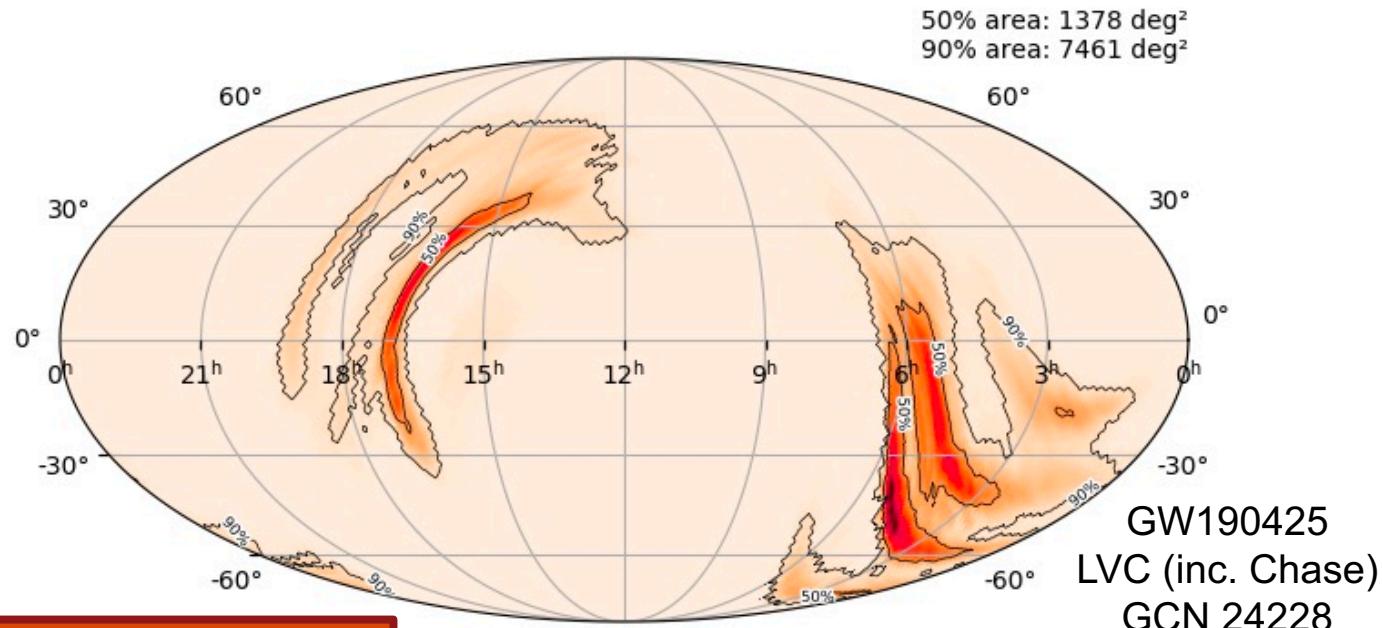
Gamma-ray  
Burst

Kilonova

Afterglow

# Searching for a Kilonova

# Searching for a Kilonova



Full moon only covers  
0.2 deg<sup>2</sup> of the sky

# LANL Kilonova Simulations

- **Radiative transfer simulations**
  - SuperNu (Wollaeger et al. 2013; Wollaeger & van Rossum 2014)
- **Multi-dimensional simulations yielding spectra and lightcurves of kilonovae**
- **Relies on LANL suite of atomic physics codes**
  - Fontes et al. 2015; Fontes et al. 2020
- **Relies on nucleosynthesis results from WinNet code**
  - Winteler et al. 2012; Korobkin et al. 2012
- **Input decay product thermalization model**
  - Barnes et al. 2016

# LANL Kilonova Simulations

- **New simulations recently made public**

- Wollaeger, Fryer, Chase et al. 2021 (arXiv: 2105.11543)

**Publicly available:** <https://zenodo.org/record/5745556>

- **Used in several previous publications**

- Evans et al. 2017
- Kasliwal et al. 2017
- Tanvir et al. 2017
- Troja et al. 2017
- Wollaeger et al. 2018
- Wollaeger et al. 2019
- Even et al. 2020
- Thakur et al. (inc. Chase) 2020
- O'Connor et al. (inc. Chase) 2021
- Korobkin et al. (inc. Chase) 2021
- Bruni et al. 2021
- Dichiara et al. (inc. Chase) 2021
- Ristic et al. (inc. Chase) 2022
- Chase et al. 2022

# LANL Kilonova Simulations

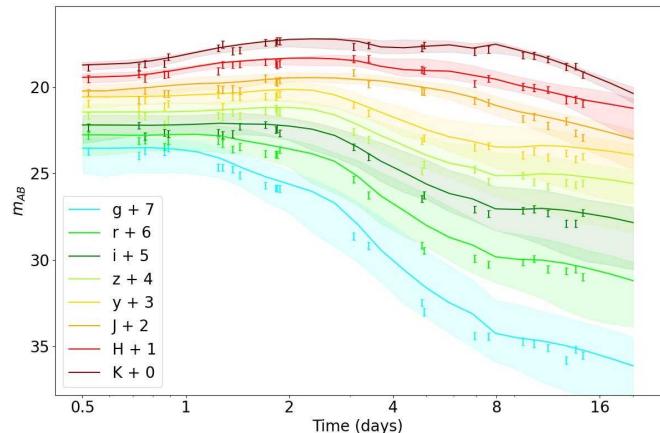
- **New simulations recently made public**

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- **Used in several previous publications**

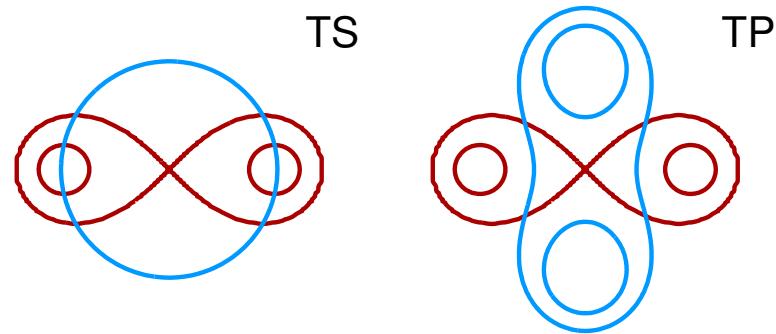
- Evans et al. 2017
- Kasliwal et al. 2017
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- Korobkin et al. (inc. Chase) 2021
- Bruni et al. 2021
- Dichiara et al. (inc. Chase) 2021
- **Ristic et al. (inc. Chase) 2022**
- Chase et al. 2022



Ristic et al. 2022  
arXiv: 2105.07013

# LANL Kilonova Simulations

- **Dynamical ejecta**
  - Low- $Y_e$ , lanthanide-rich, “red”
- **Wind ejecta**
  - High- $Y_e$ , lanthanide-poor, “blue”

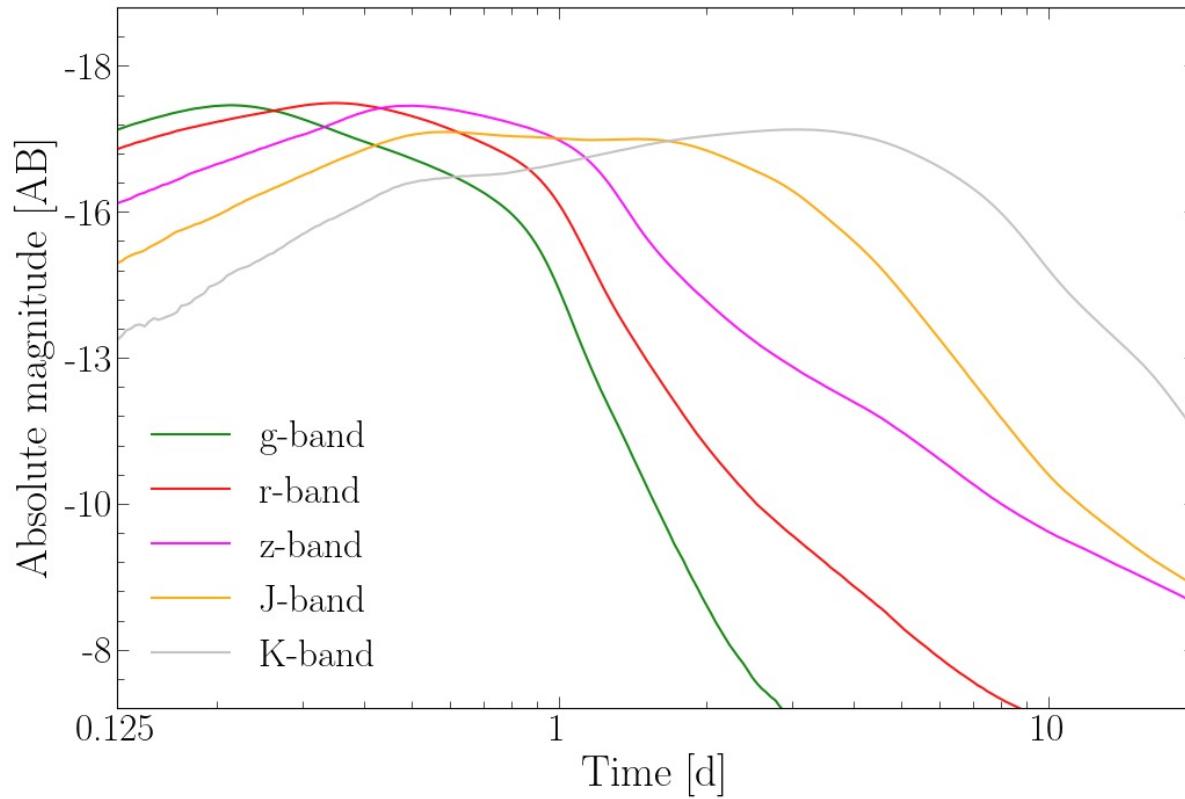


900 simulations!

**Table 2.** Properties of LANL kilonova simulations (adapted from Wollaeger et al. 2021).

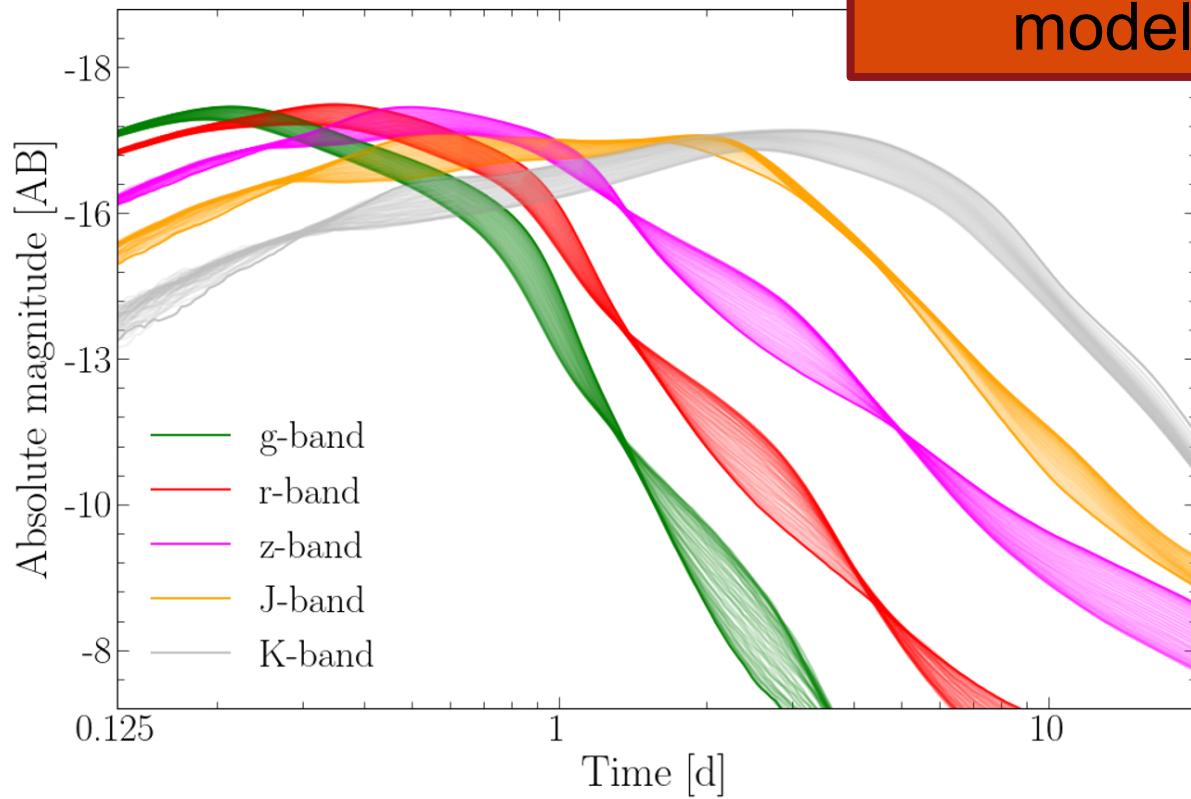
| Property                | Values   |
|-------------------------|--|
| Dyn. ejecta mass        | {0.001, 0.003, 0.01, 0.03, 0.1} $M_\odot$                                |
| Wind ejecta mass        | {0.001, 0.003, 0.01, 0.03, 0.1} $M_\odot$                                |
| Dyn. ejecta velocity    | {0.05, 0.15, 0.3} $c$  |
| Wind ejecta velocity    | {0.05, 0.15, 0.3} $c$  |
| Dyn. ejecta morphology  | Toroidal (T; Cassini oval family; Korobkin et al. 2021)                  |
| Wind ejecta morphology  | Spherical (S) or “Peanut” (P; Cassini oval family; Korobkin et al. 2021) |
| Dyn. ejecta composition | initial $Y_e = 0.04$ (see Table 2 in Wollaeger et al. 2021)              |
| Wind ejecta composition | initial $Y_e = 0.27$ or $0.37$ (see Table 2 in Wollaeger et al. 2021)    |

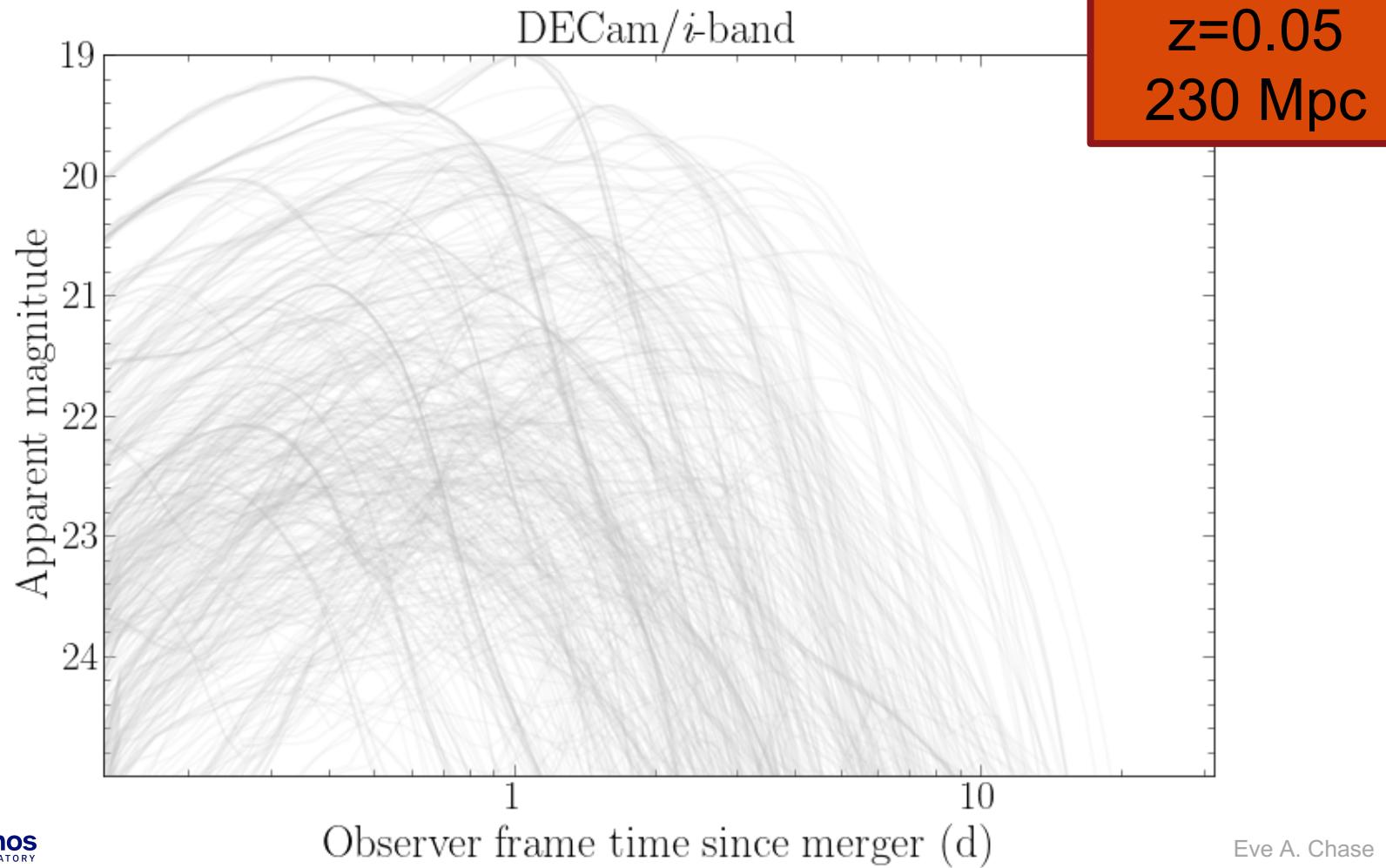
# Kilonova Lightcurves

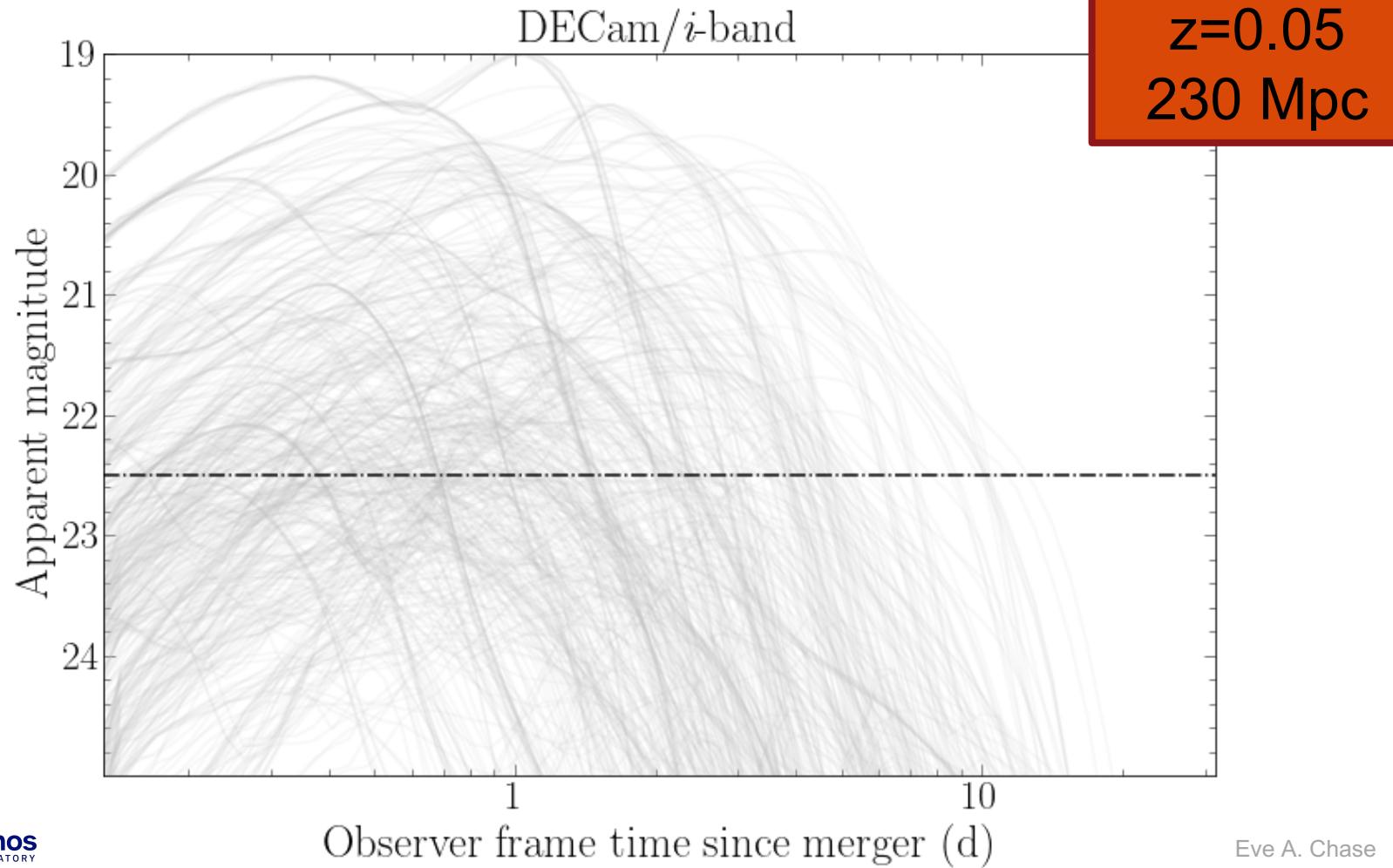


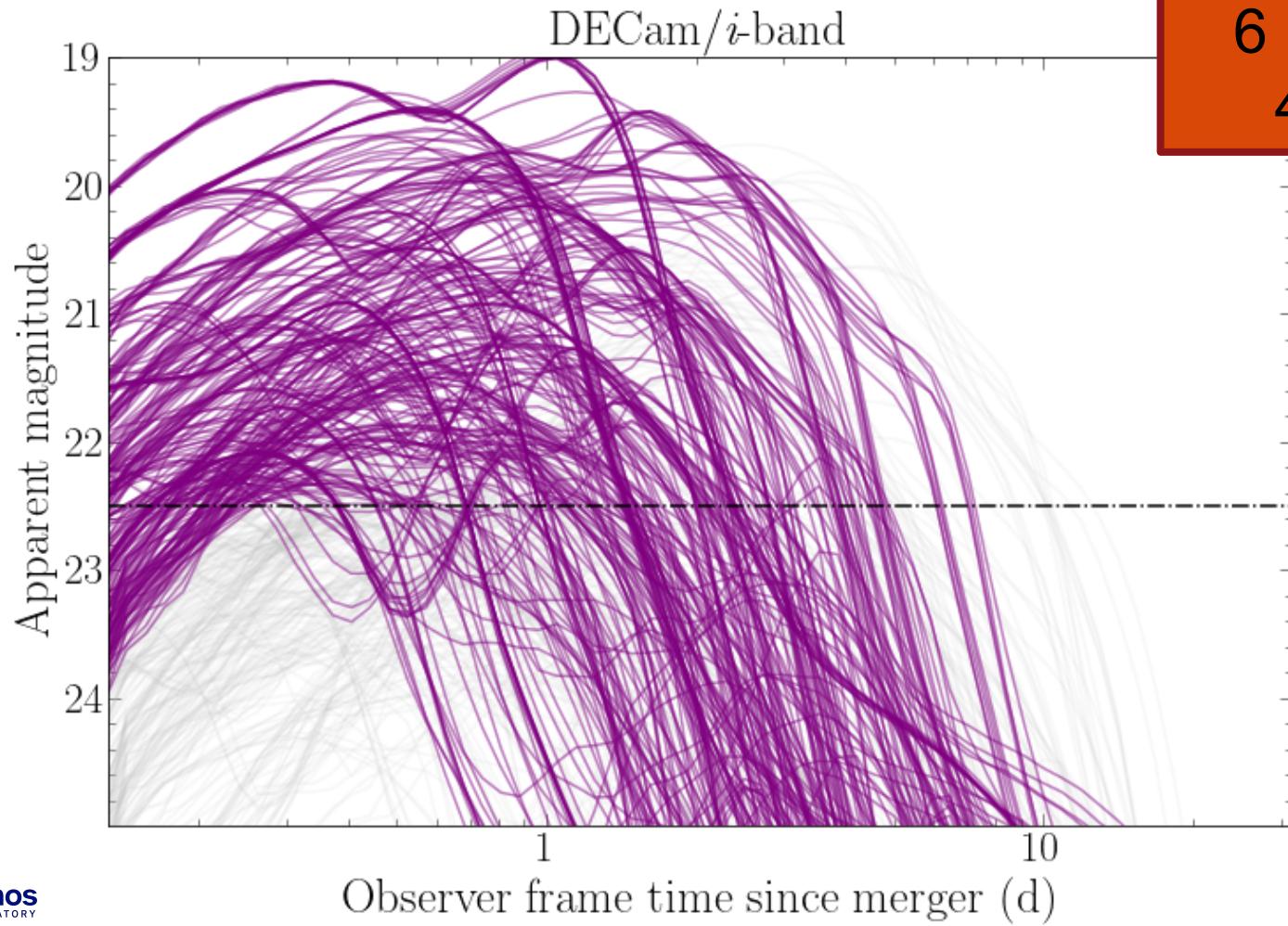
# Kilonova Lightcurves

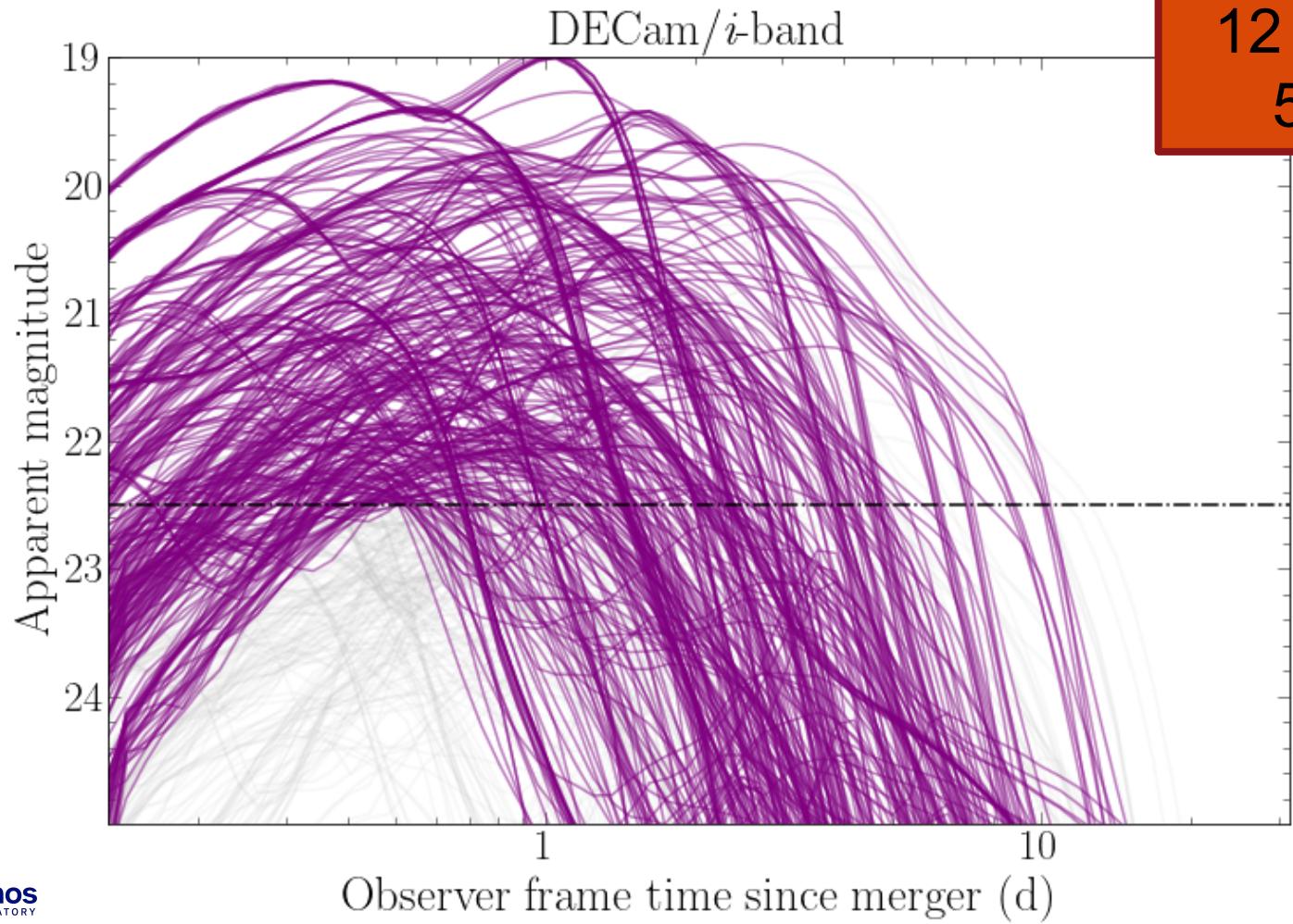
900\*54 = 48,600  
models!

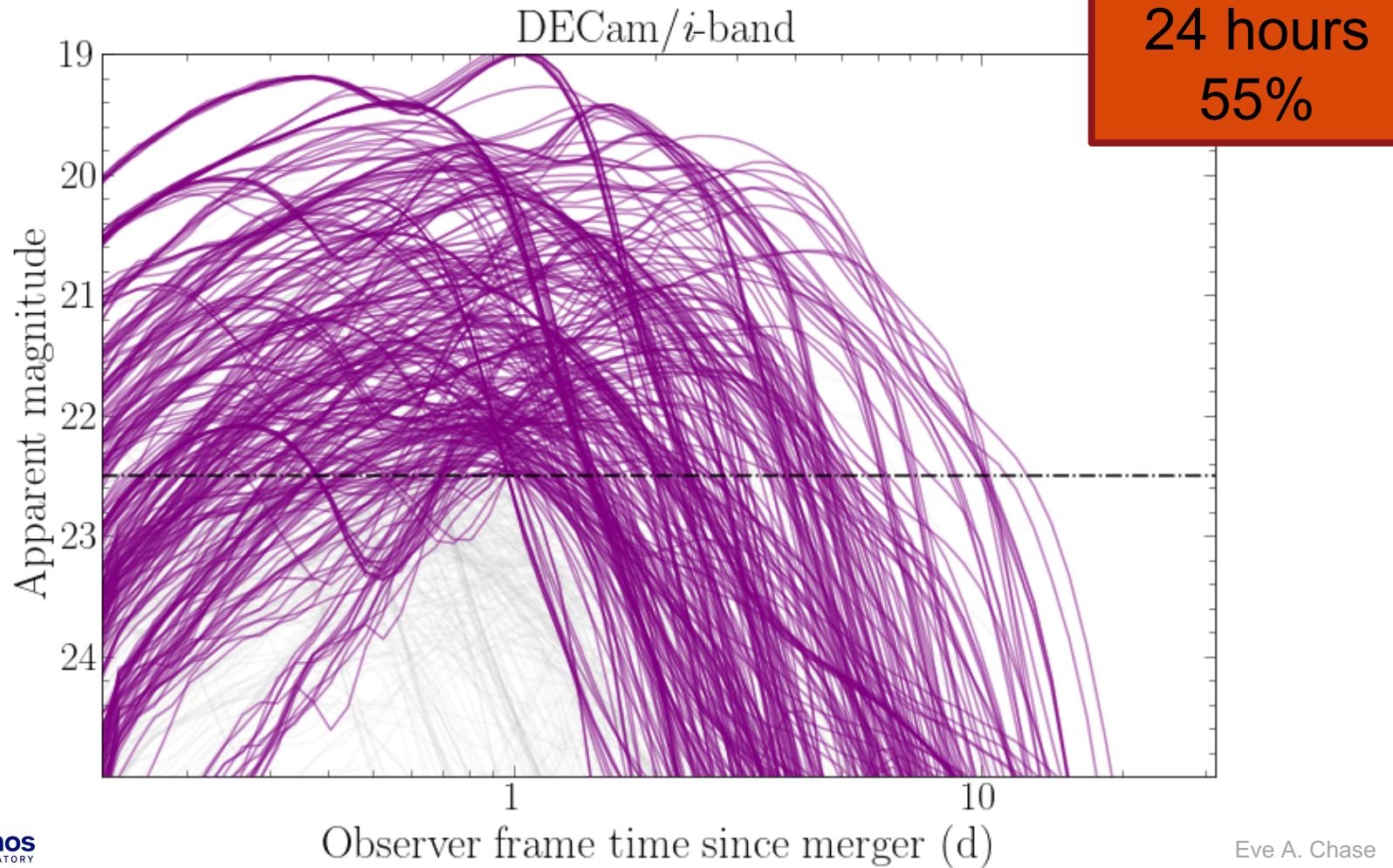


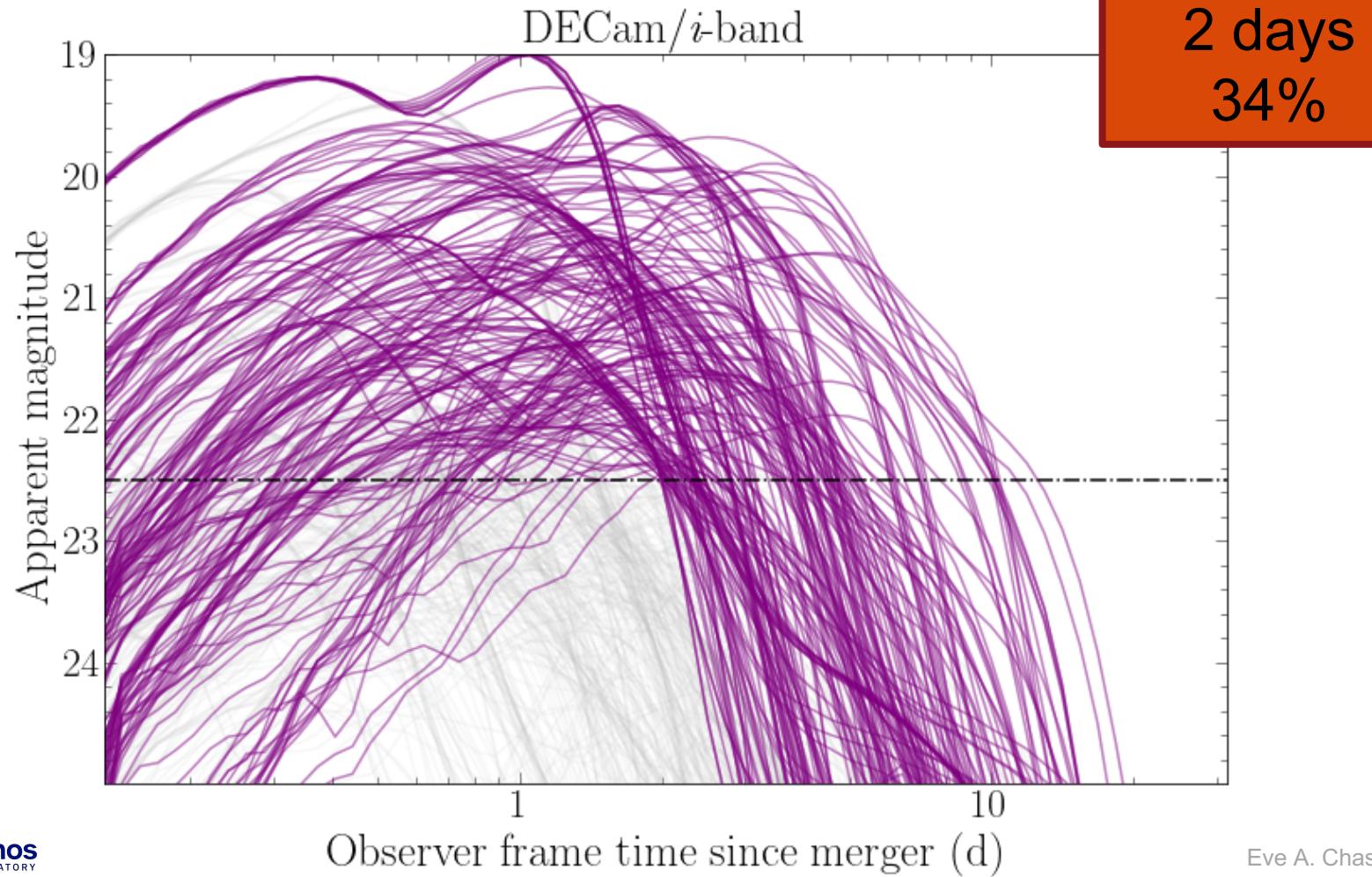


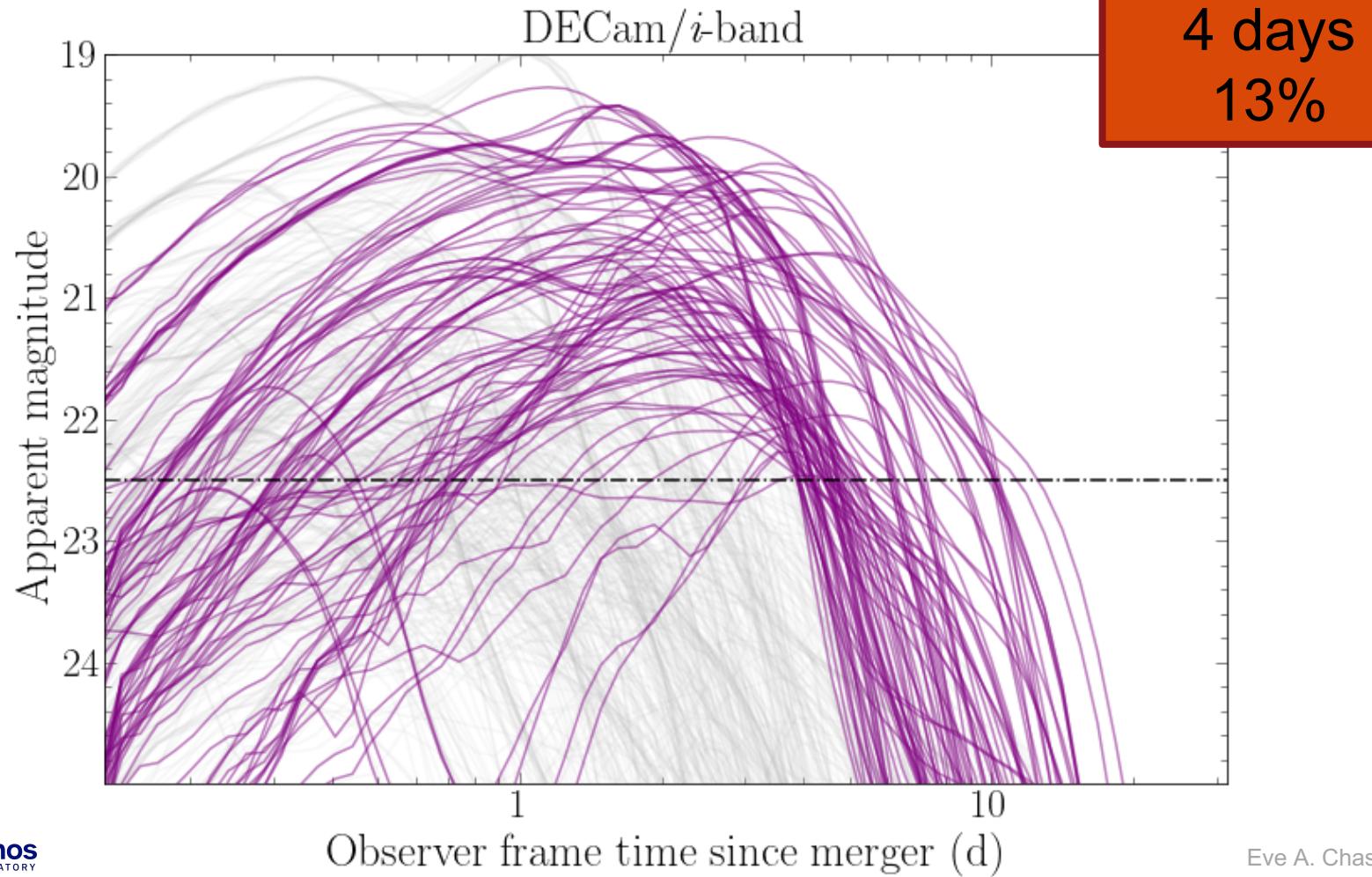


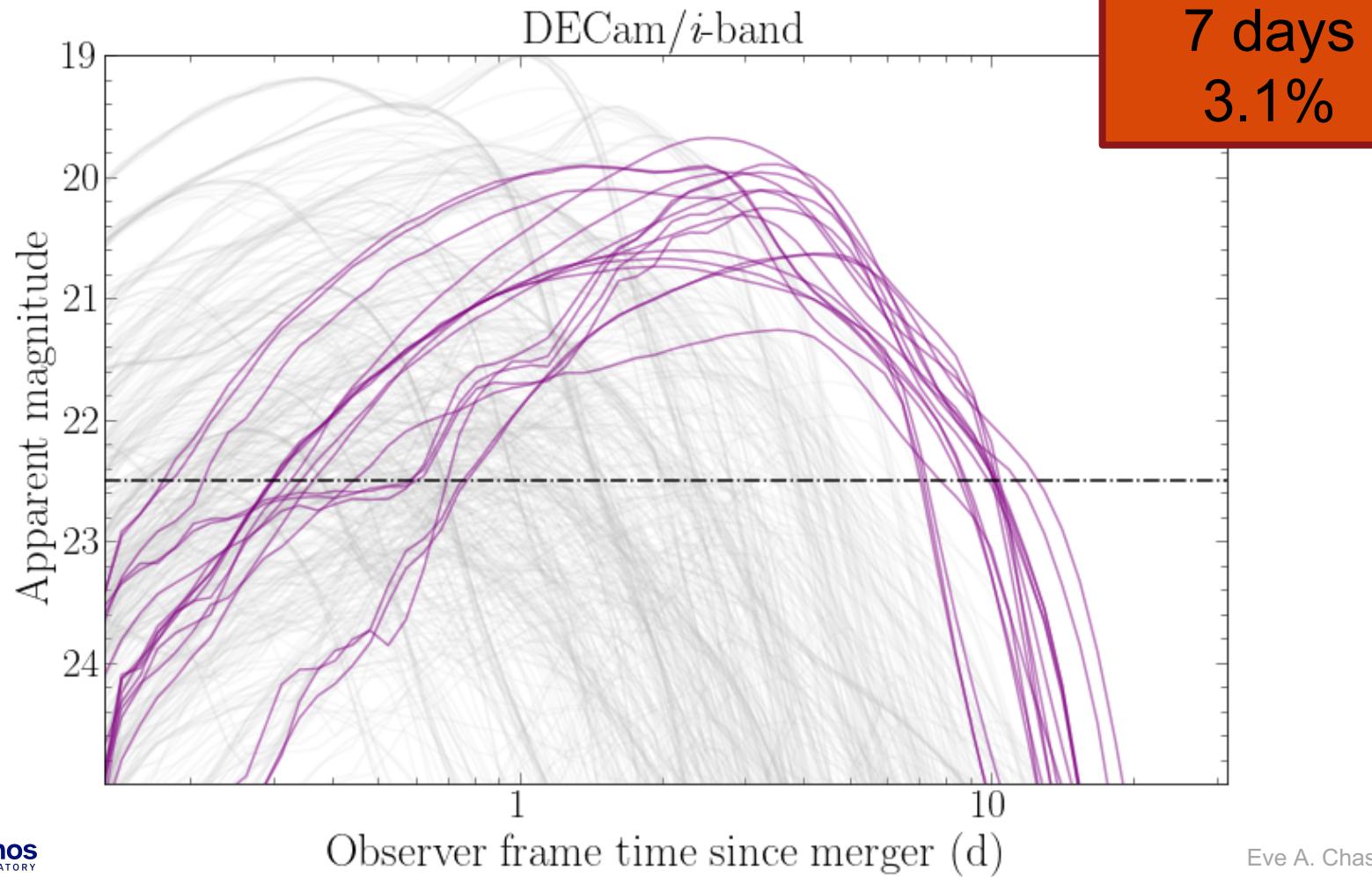


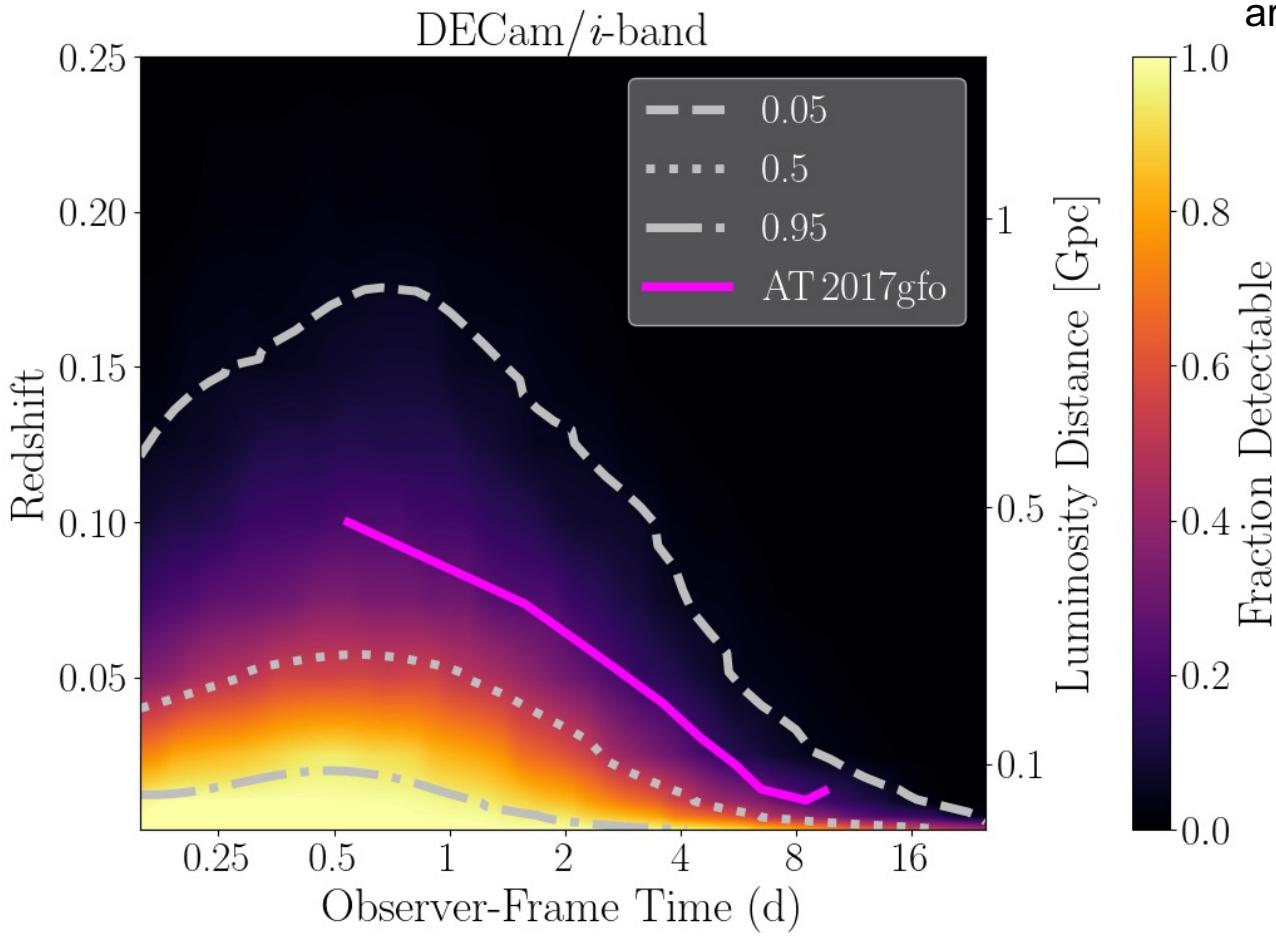








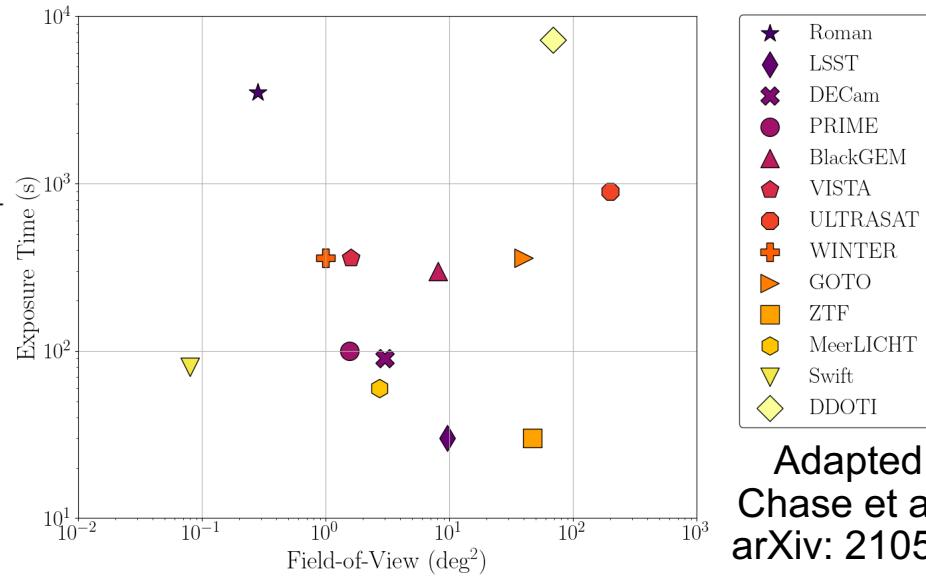




# Wide-Field Instruments

**Table 1.** Kilonova detectability metrics for a wide-field instruments.

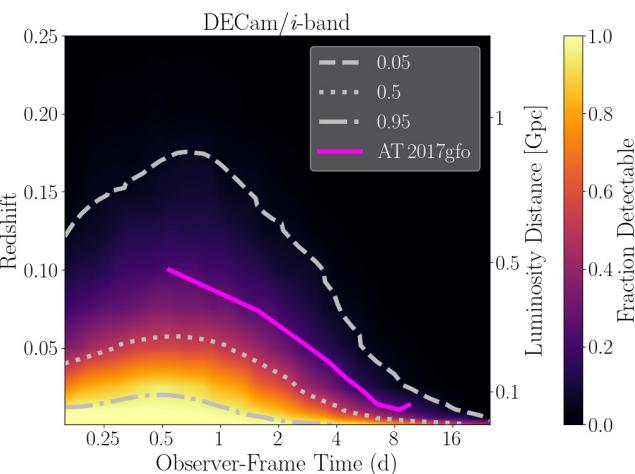
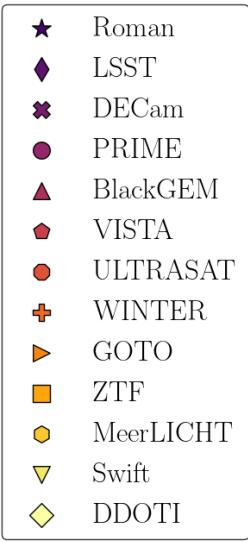
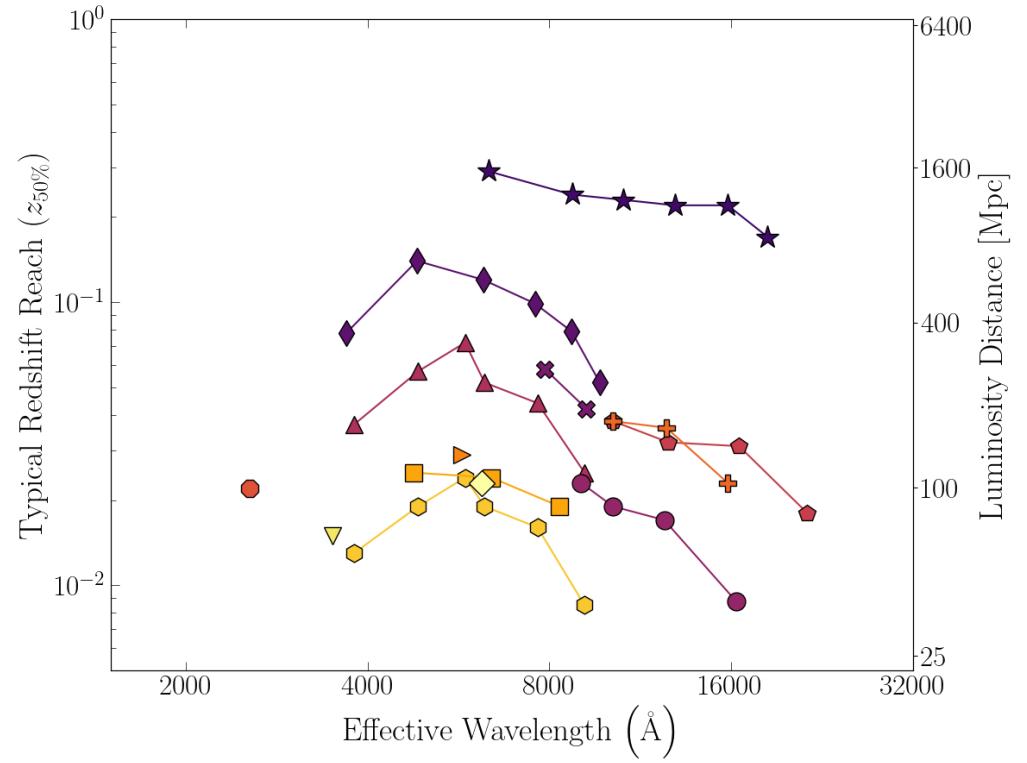
| Instrument | FoV (deg <sup>2</sup> ) | Exp. Time (s) | Filters                 |
|------------|-------------------------|---------------|-------------------------|
| BlackGEM   | 8.1                     | 300           | <i>ug(q)riz</i>         |
| DDOTI      | 69                      | 7200          | <i>w</i>                |
| DECam      | ~3                      | 90            | <i>iz</i>               |
| GOTO       | 40                      | 360           | <i>L</i>                |
| LSST       | 9.6                     | 30            | <i>ugrizy</i>           |
| MeerLICHT  | 2.7                     | 60            | <i>ug(q)riz</i>         |
| PRIME      | 1.56                    | 100           | <i>ZYJH</i>             |
| Roman      | 0.28                    | 67            | <i>RZYJHF</i>           |
| Swift/UVOT | 0.08                    | 80            | <i>u</i>                |
| ULTRASAT   | 200                     | 900           | <i>NUV</i>              |
| VISTA      | 1.6                     | 360           | <i>YJHK<sub>s</sub></i> |
| WINTER     | 1.0                     | 360           | <i>YJH<sub>s</sub></i>  |
| ZTF        | 47                      | 30            | <i>gri</i>              |

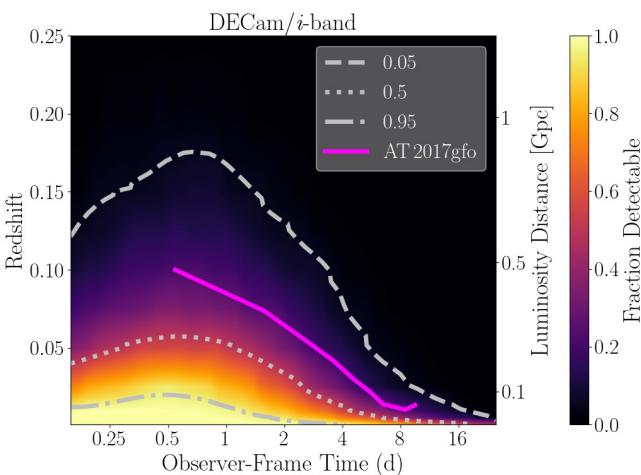
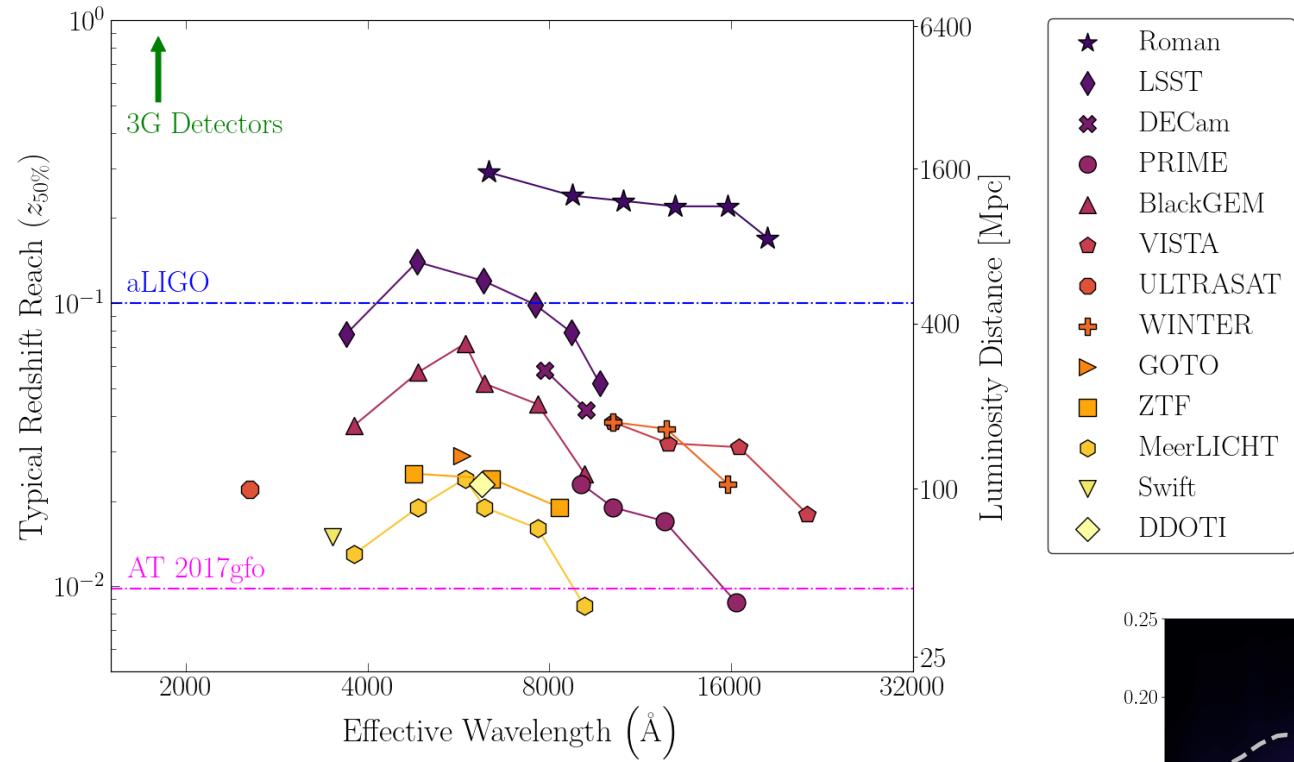


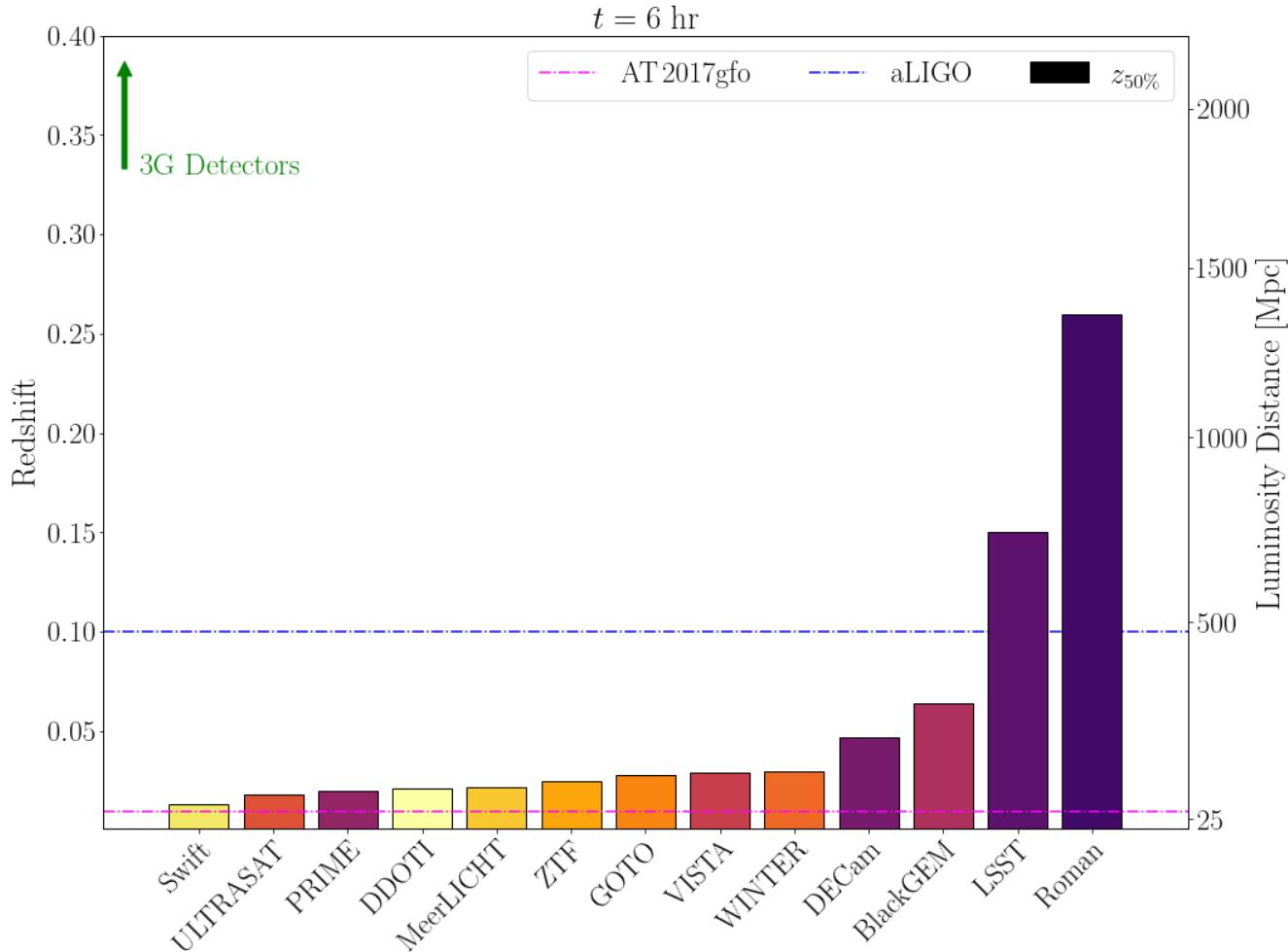
Adapted from  
Chase et al. 2022  
arXiv: 2105.12268

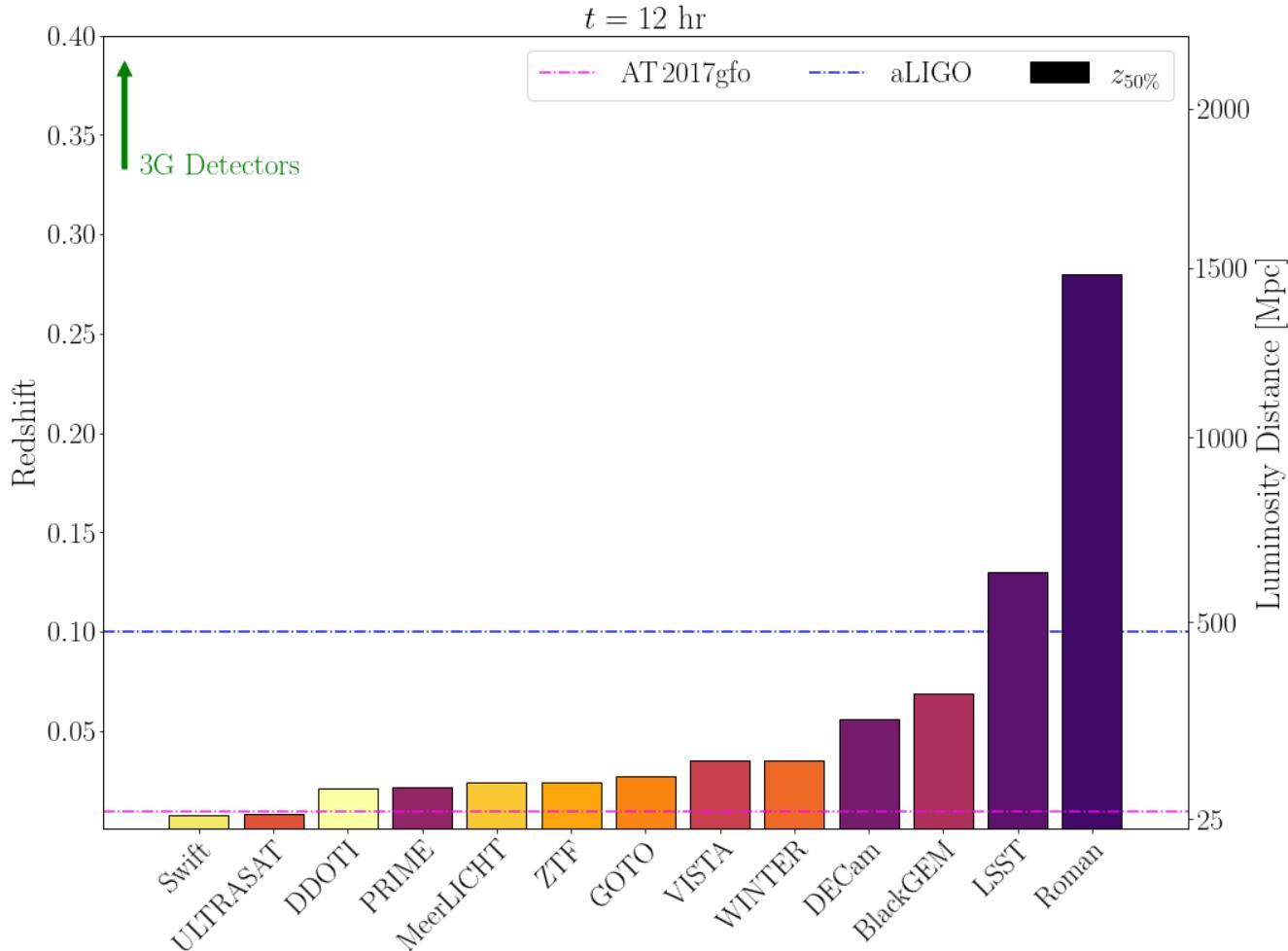
Exposure times may  
be altered to meet  
observational needs

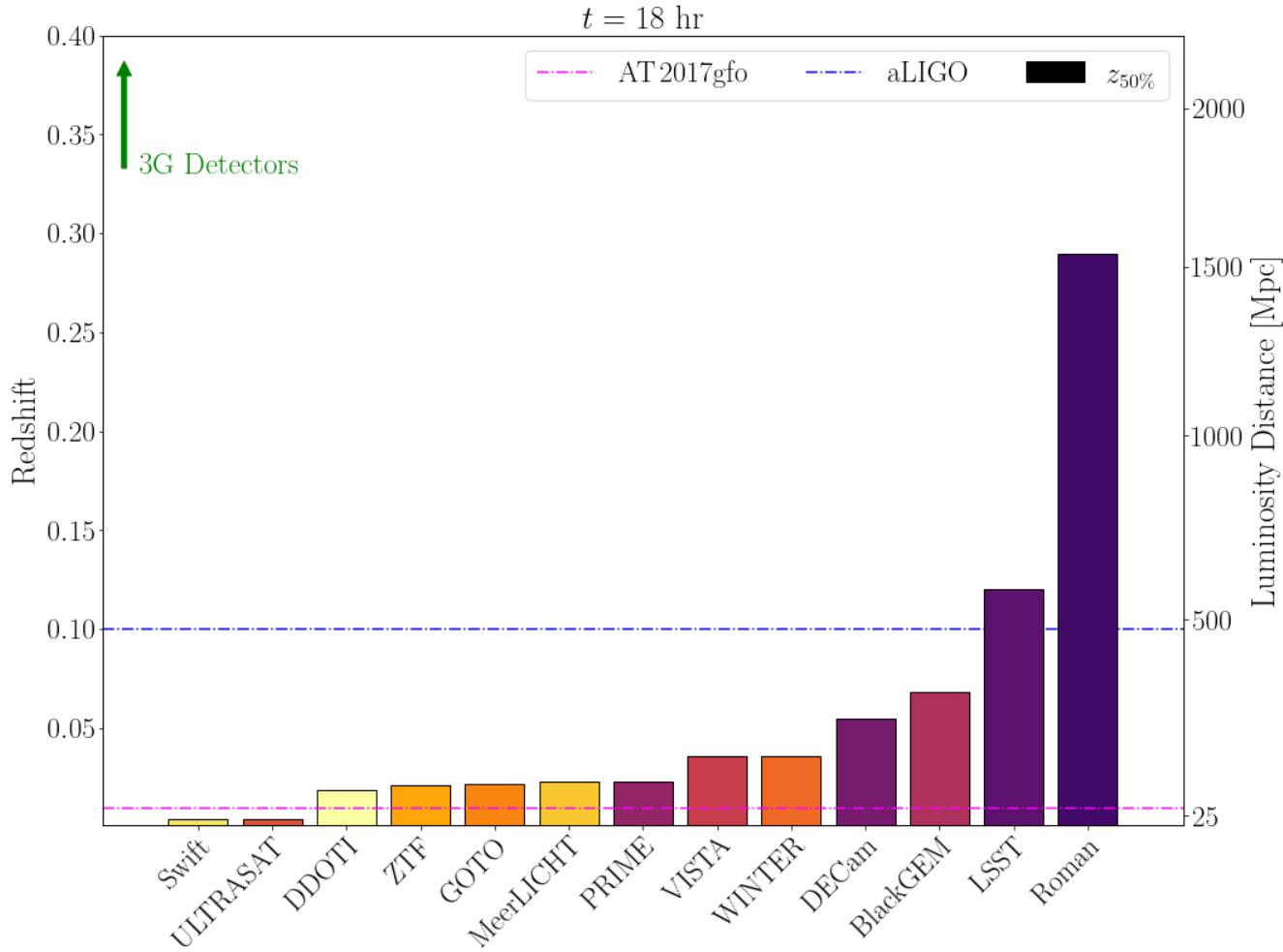
Not an exhaustive list of wide-field instruments

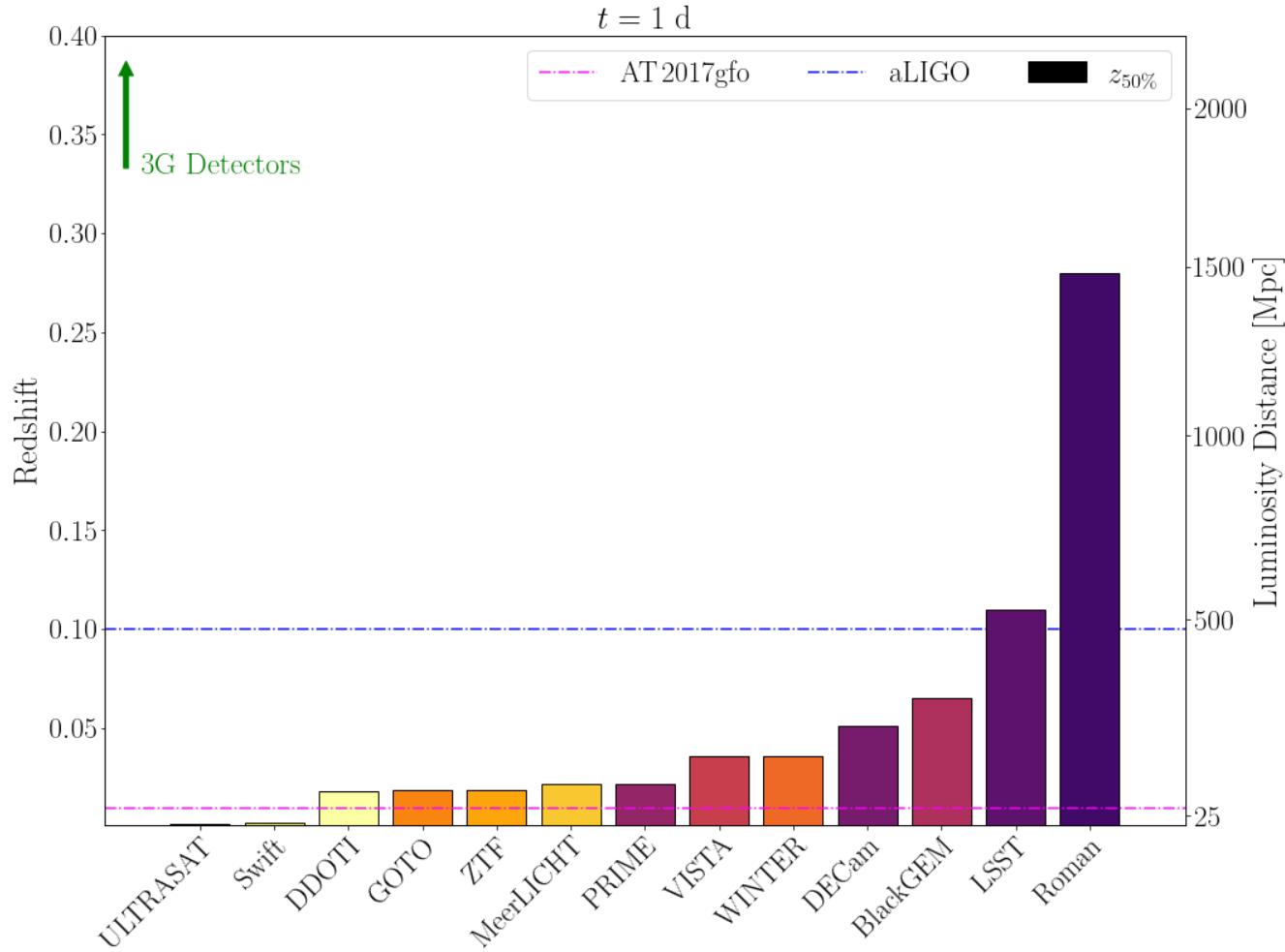


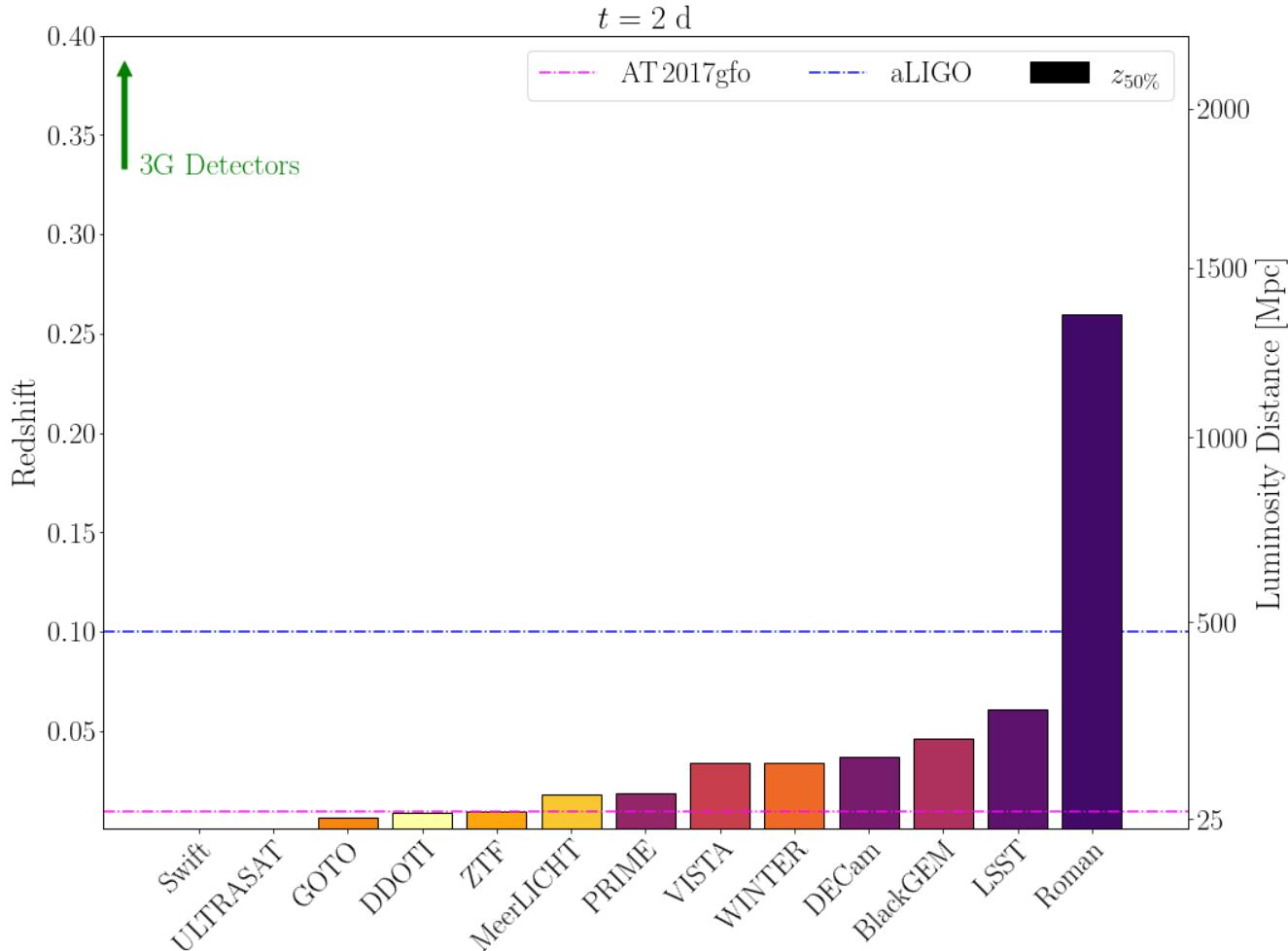


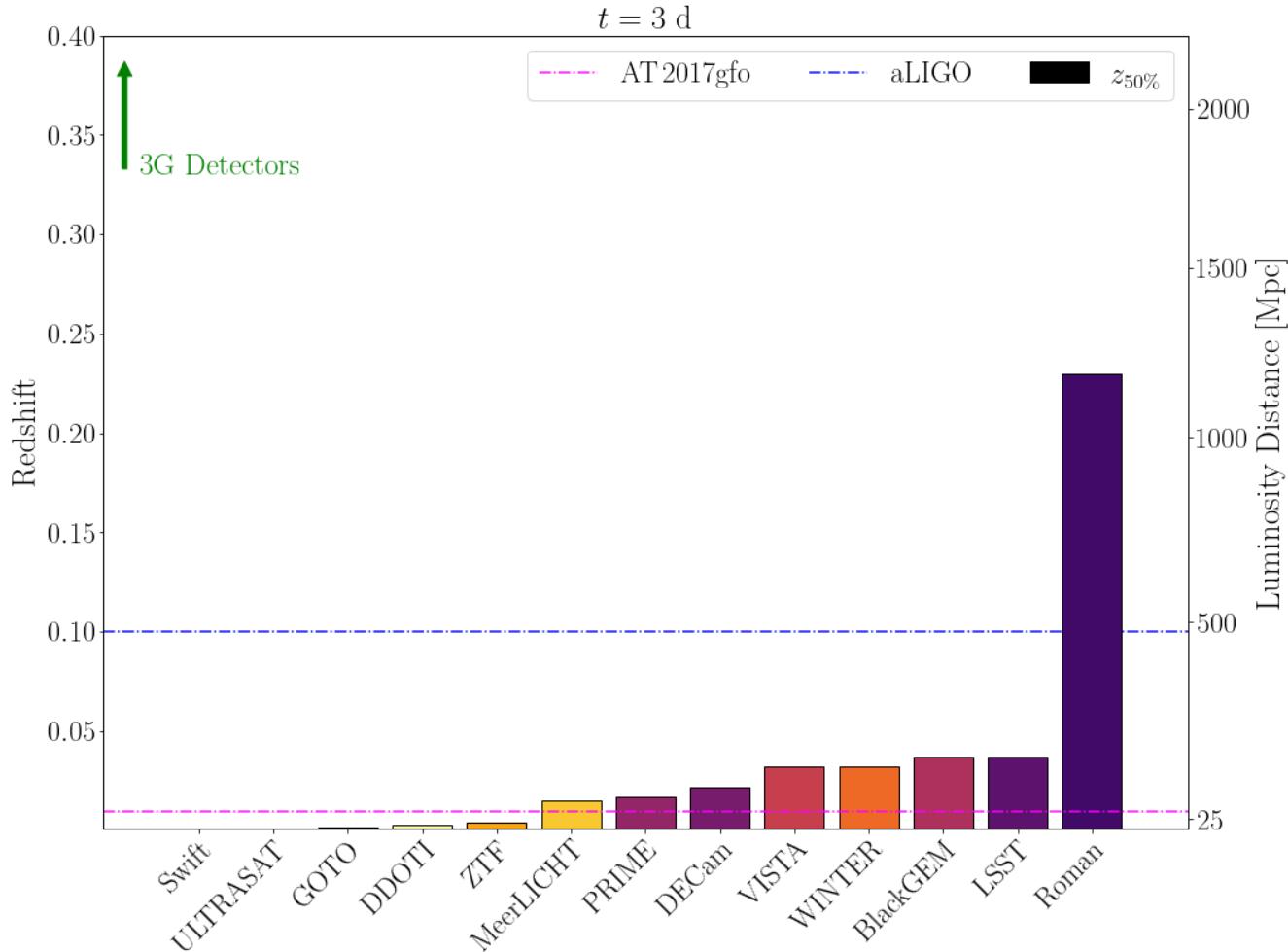


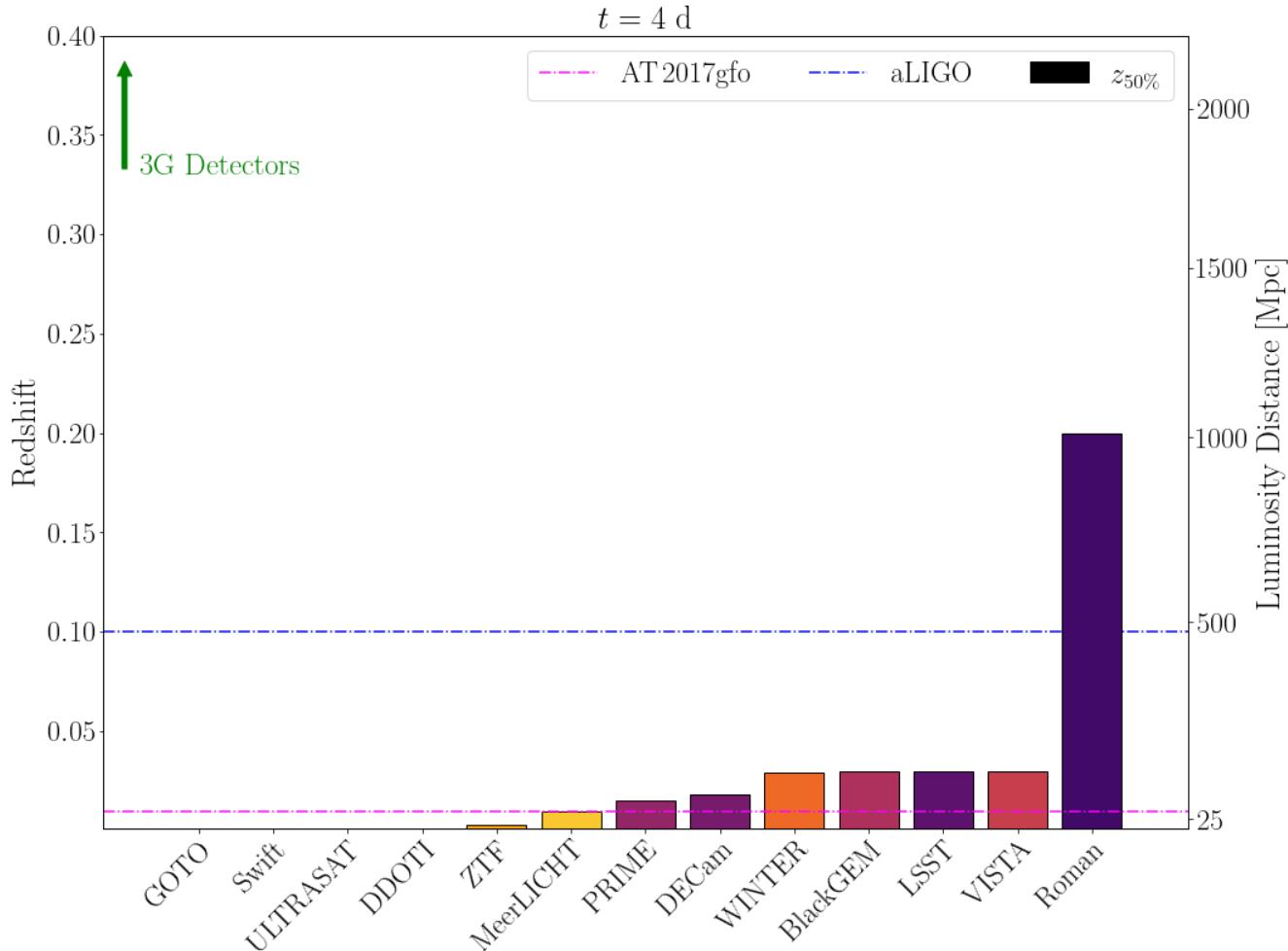


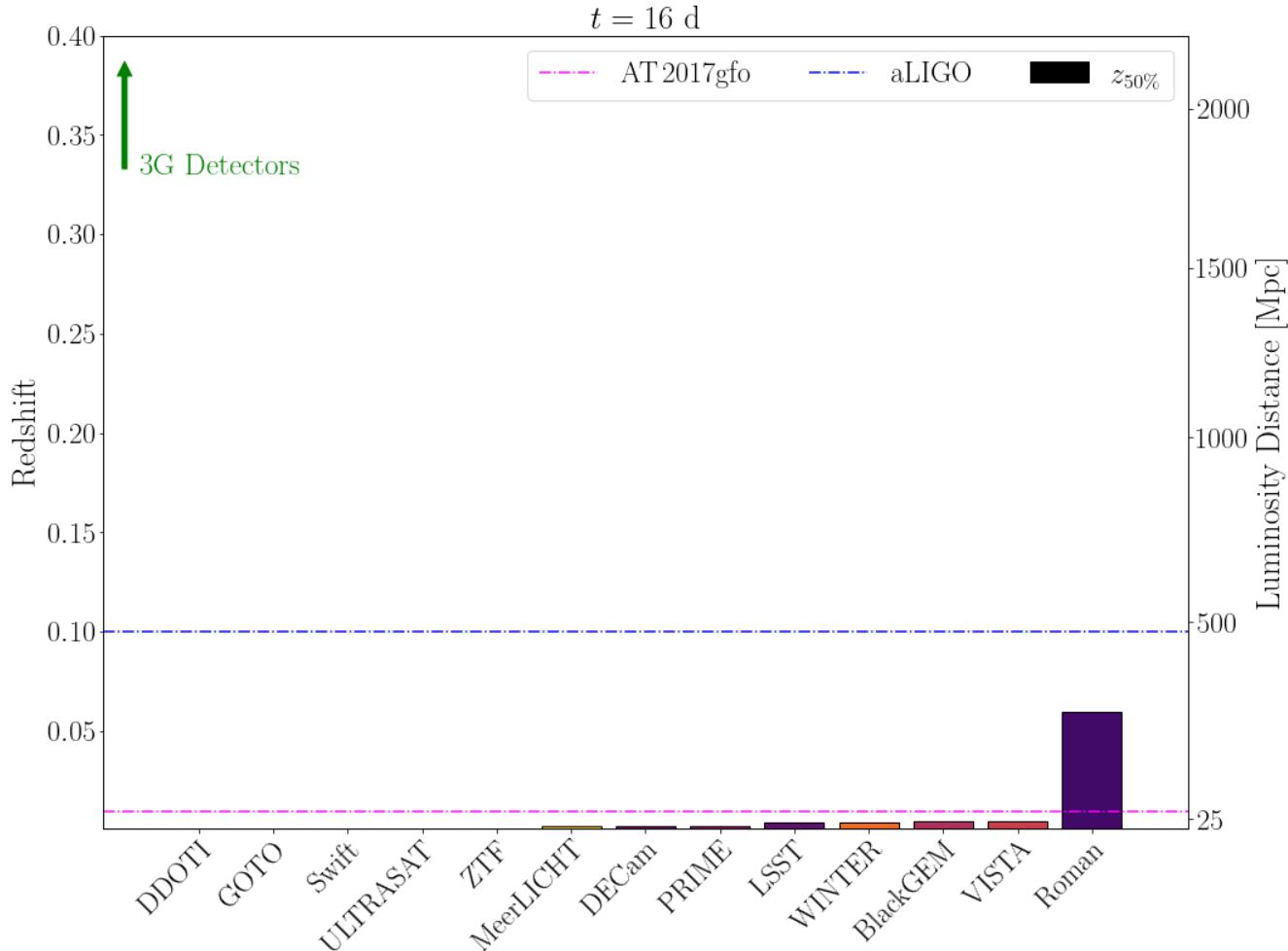




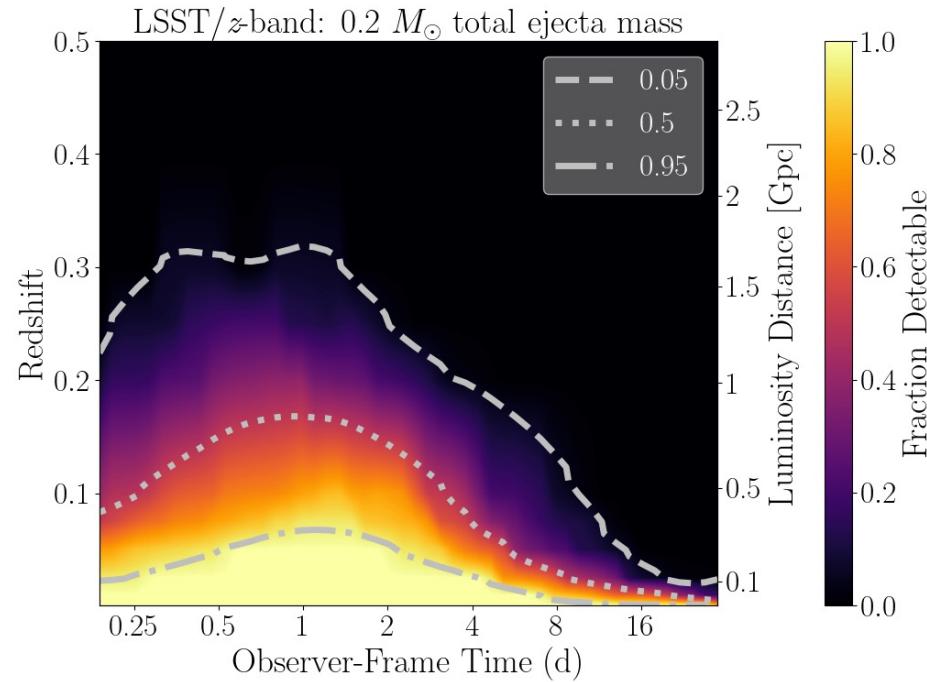
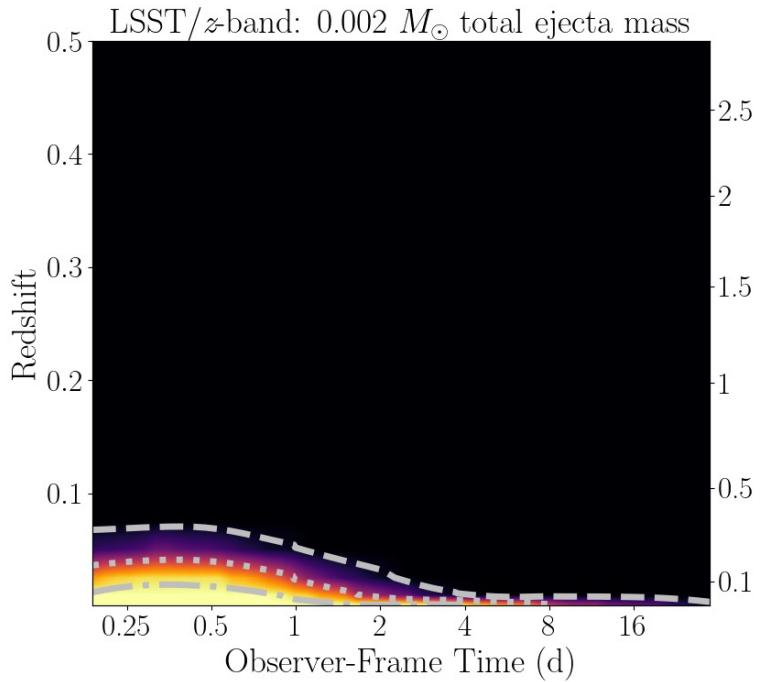






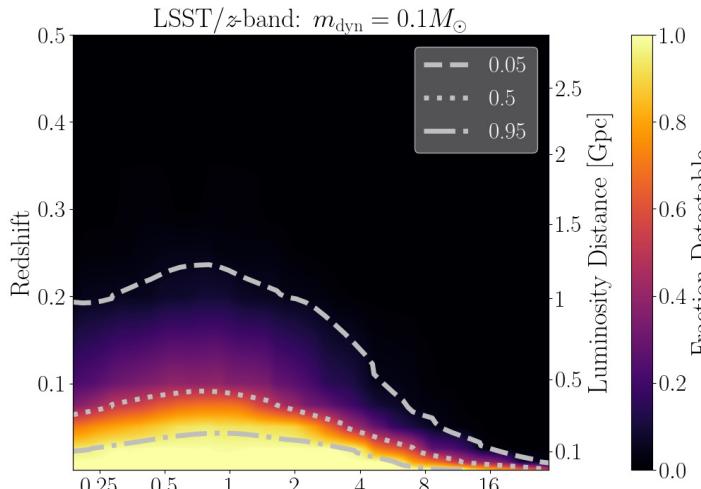
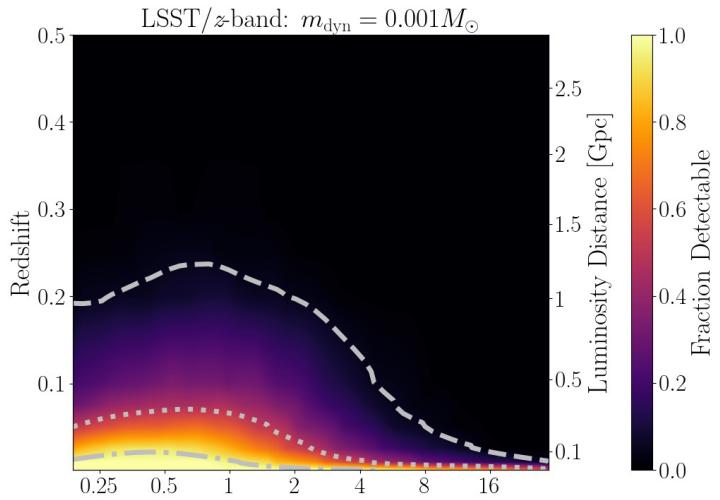


# Dependency on Kilonova Parameters

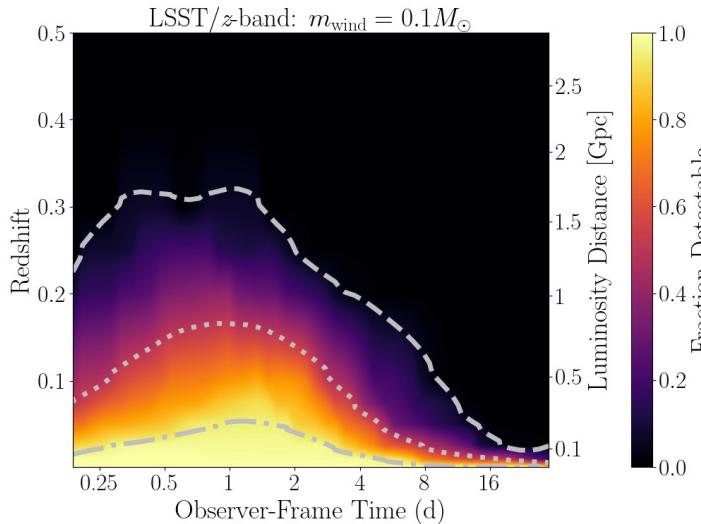
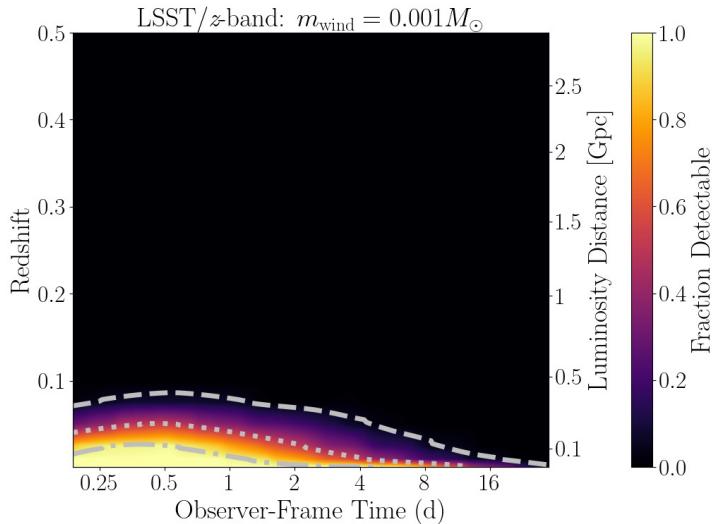


Generally, kilonovae with higher ejecta masses are detectable at larger redshifts.

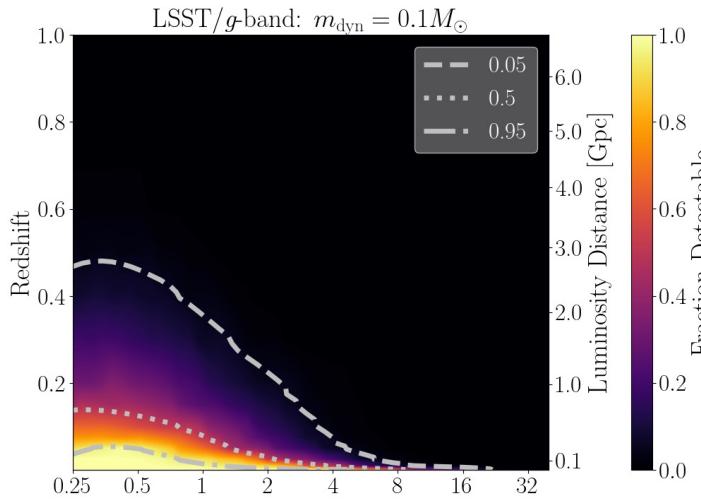
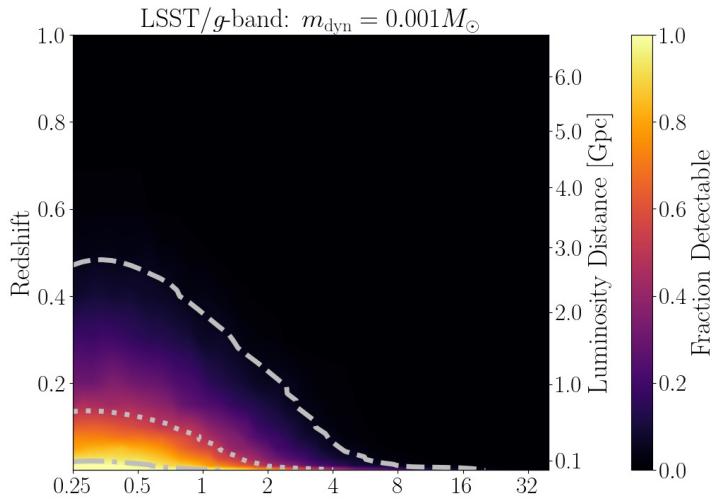
## Dynamical ejecta



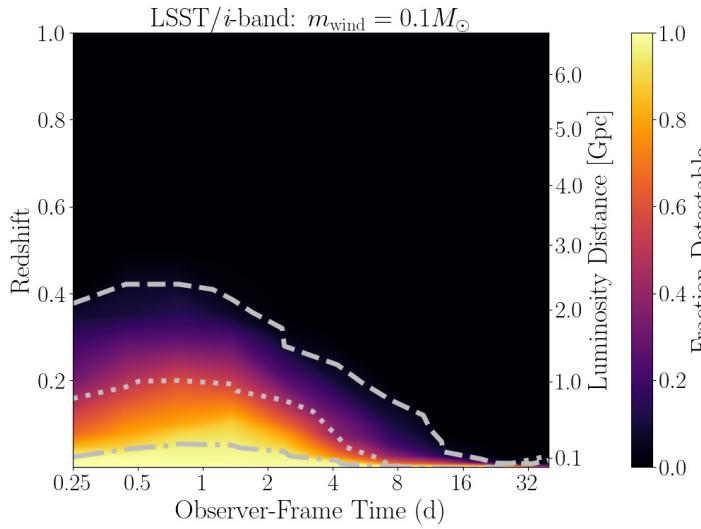
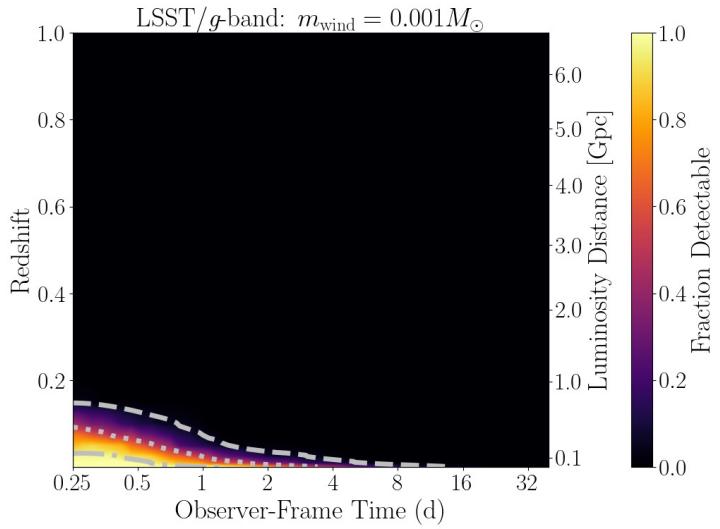
## Wind ejecta



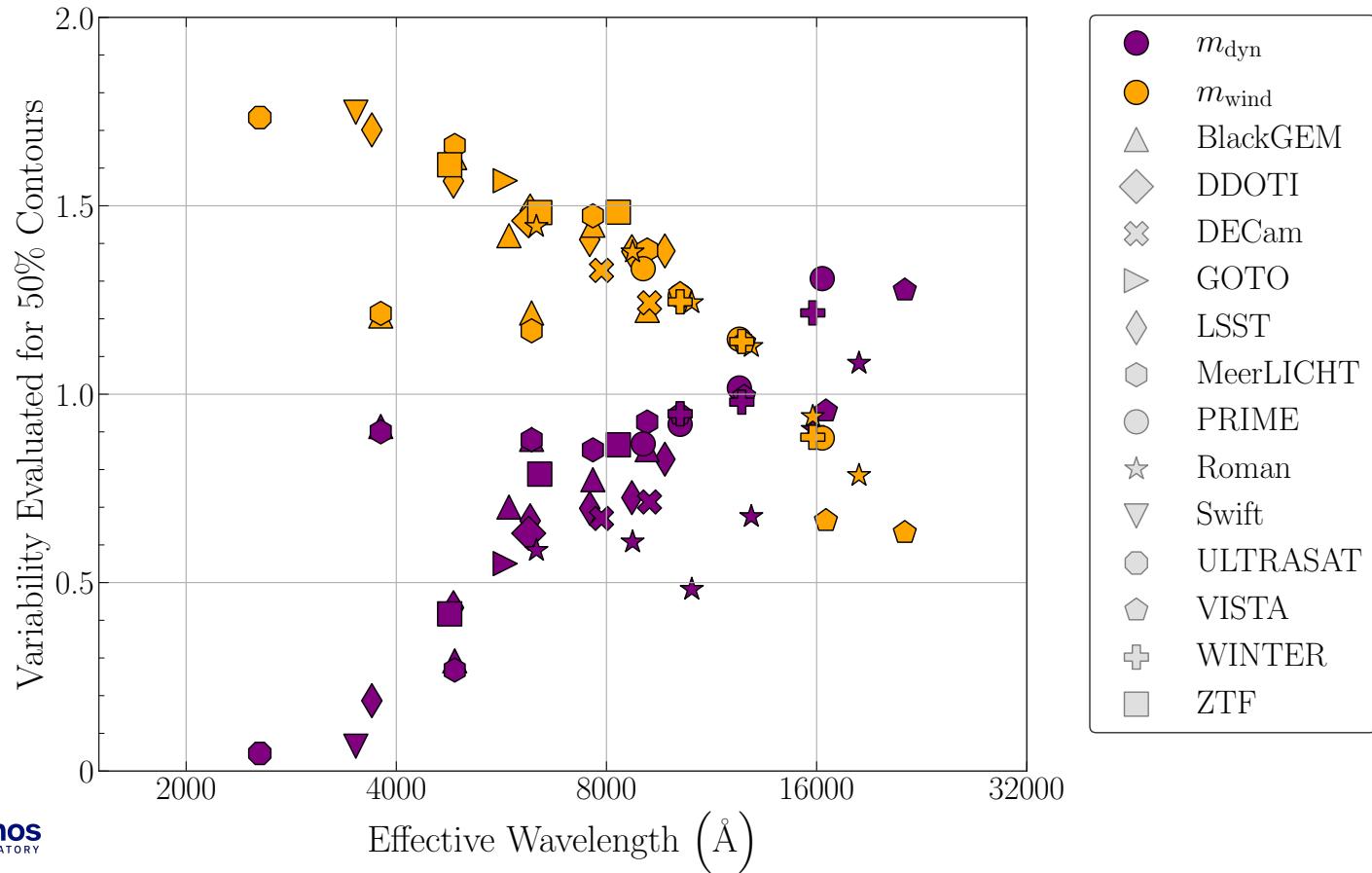
## Dynamical ejecta



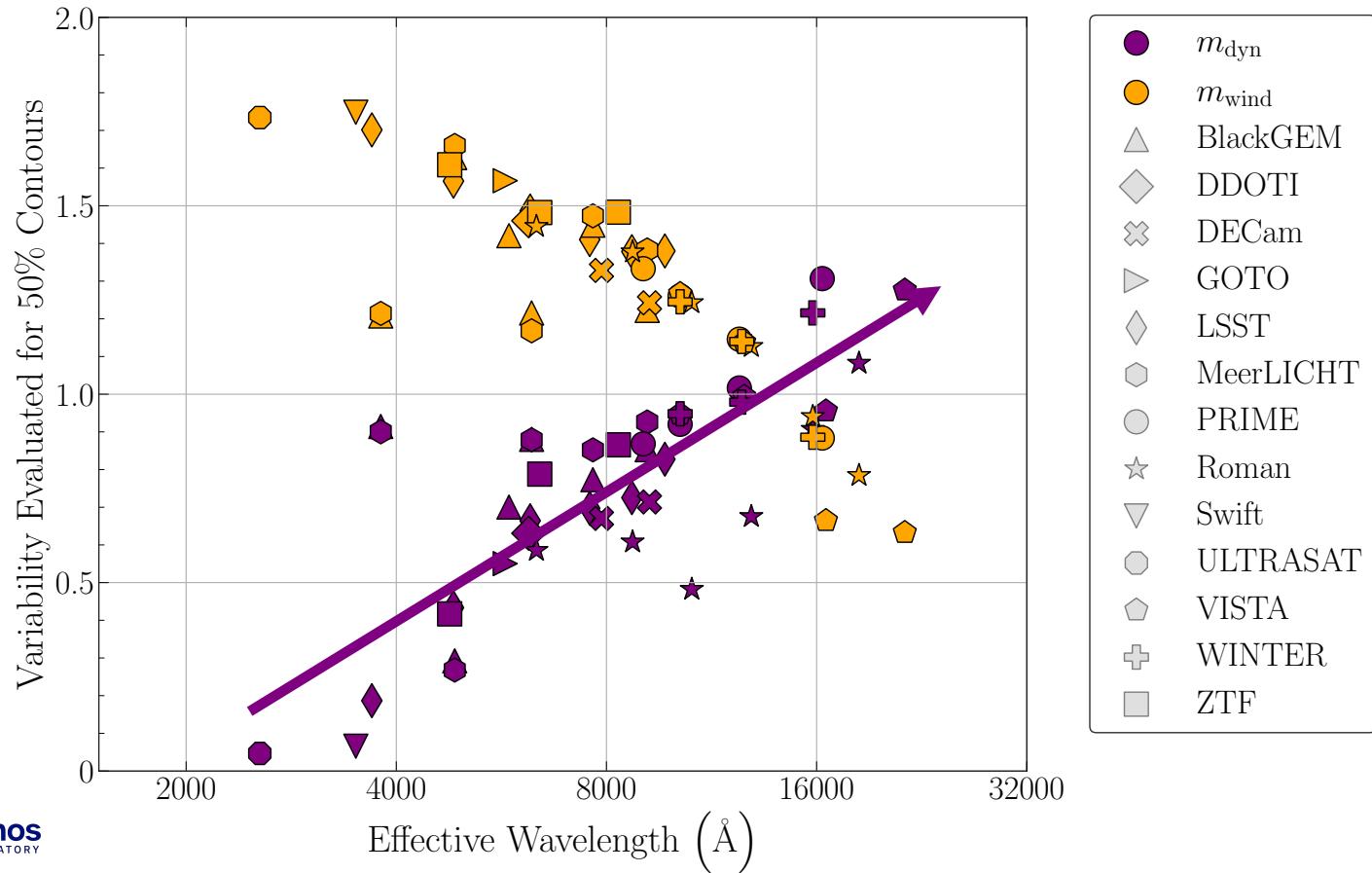
## Wind ejecta



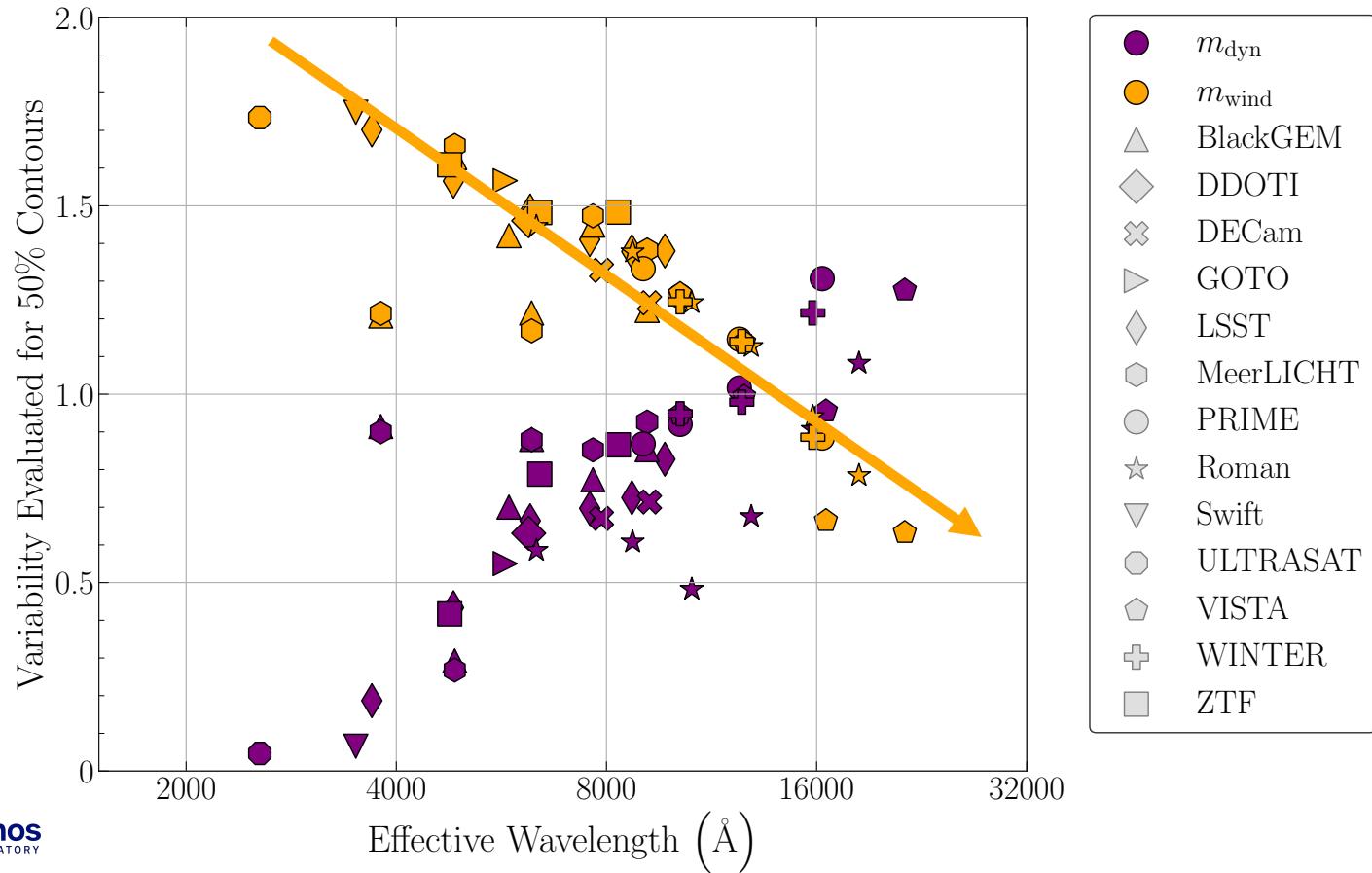
# Dependency on Kilonova Parameters



# Dependency on Kilonova Parameters



# Dependency on Kilonova Parameters



# Kilonova Detectability Conclusions

- A diverse set of instruments increase the chances of detecting and identifying a kilonova
- Early observations increase the probability of detection
- More sensitive wide-field ultraviolet instruments are needed as GW detectors reach design sensitivity
- There is a dearth of wide-field infrared instruments

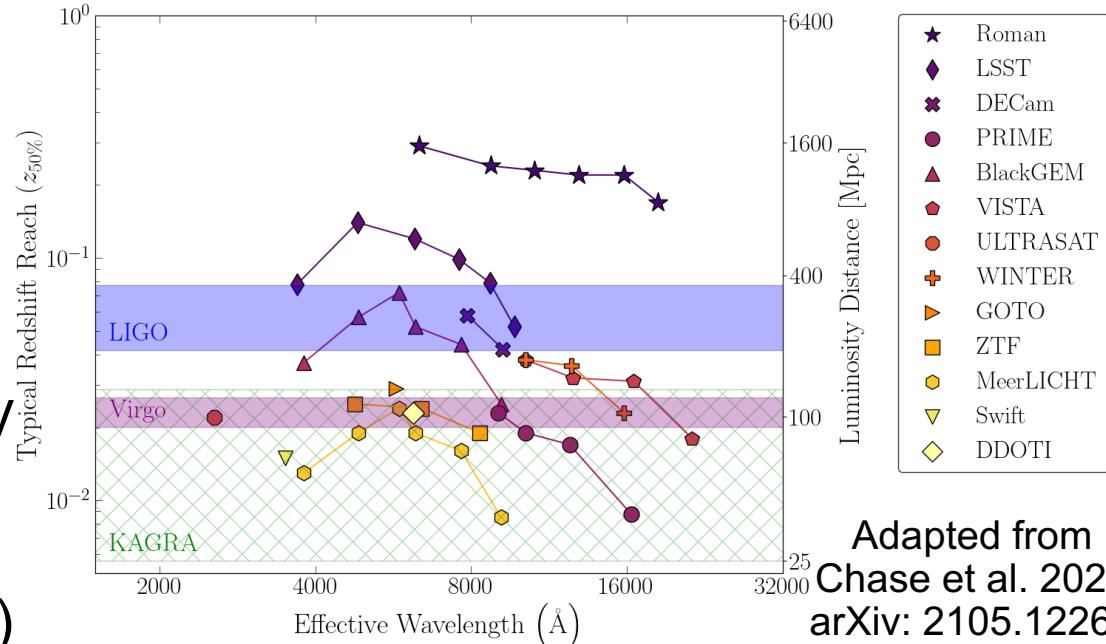
## These results are useful for...

Caveat: results are  
model-dependent

- Guiding kilonova searches following a GW detection
- Guiding kilonova searches following a sGRB observation
- Proposals for time on current and upcoming instruments
- Planning future wide-field instruments

# A Look to the Future: O4

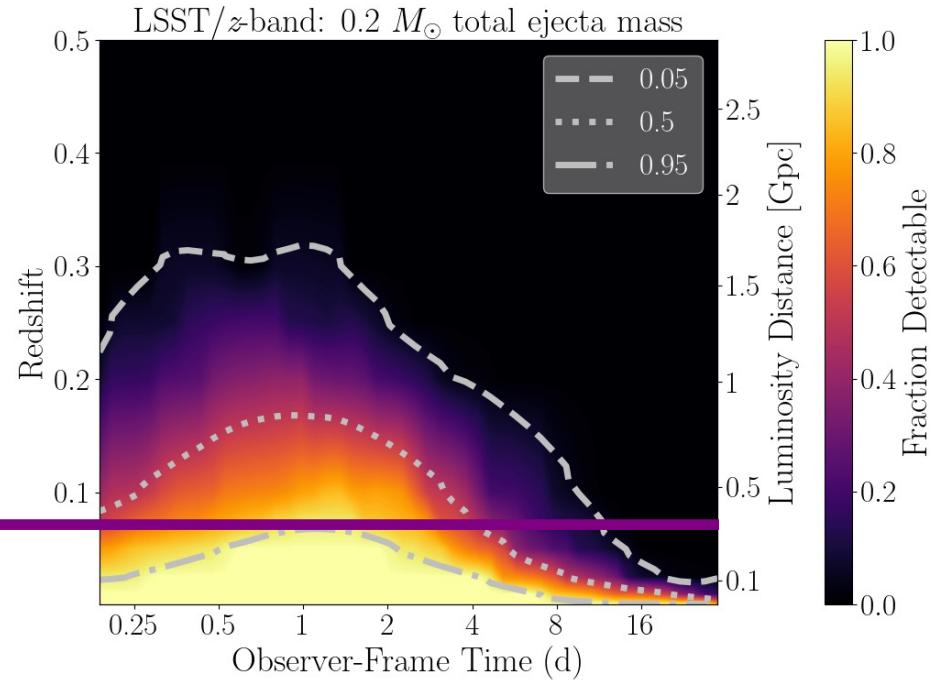
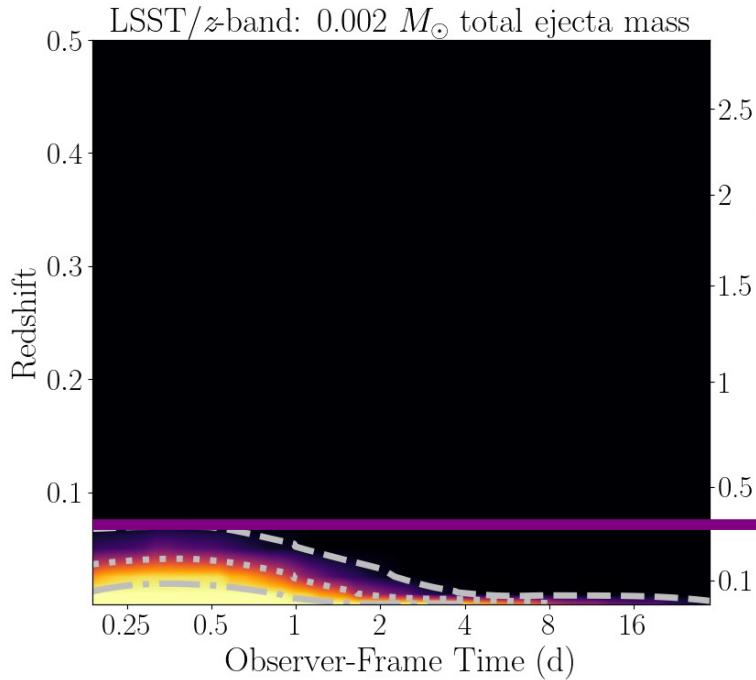
- Fourth GW observing run (O4) set to begin in December 2022, at the earliest
- 12 month observing run with LIGO, Virgo, and KAGRA detectors
- Between 0 and 62 binary neutron star mergers anticipated, with a median of 10 (LVK 2020)



Adapted from  
Chase et al. 2022  
arXiv: 2105.12268

# Extra Slides

# Inferring Properties from Non-Detections



Non-detection in  $z$ -band 1 day post-merger is  
consistent with low total ejecta masses at this redshift